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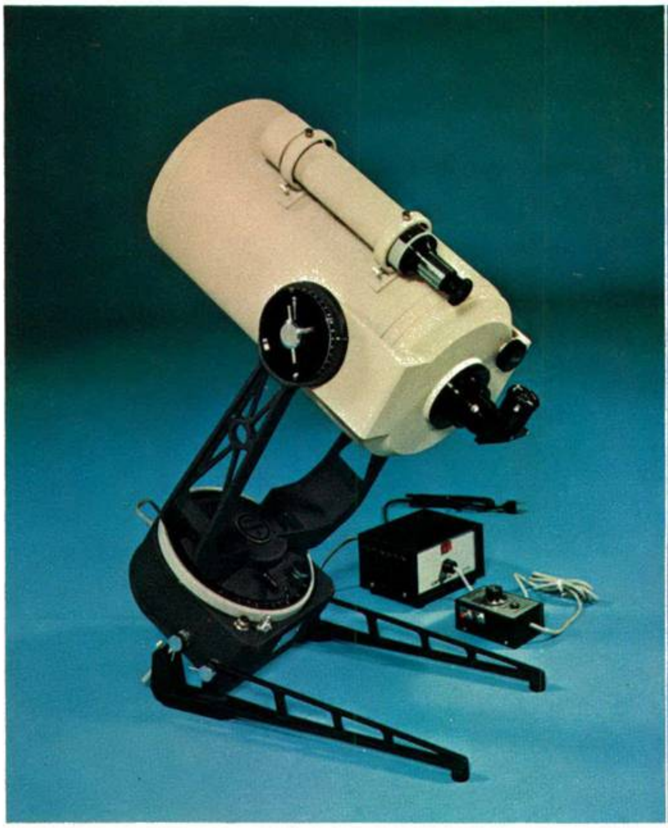

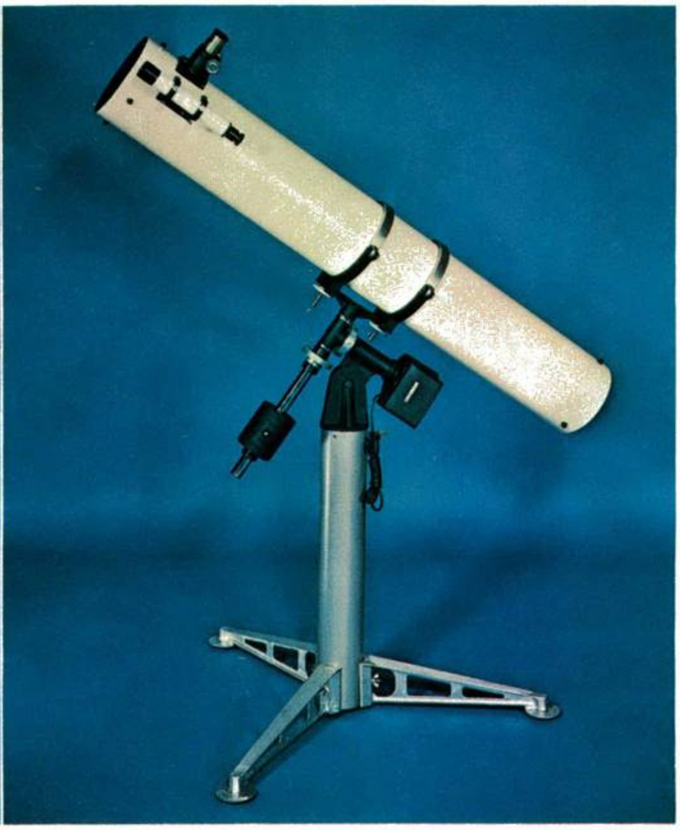

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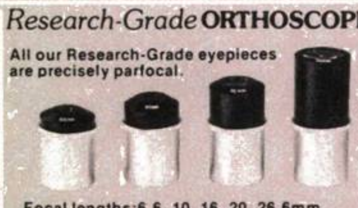

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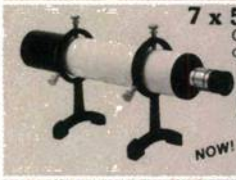

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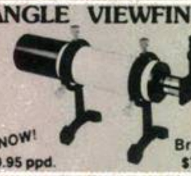

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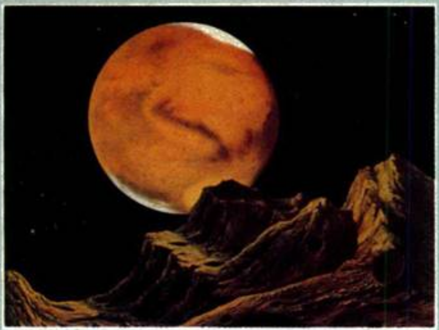
From ASTRONOMY

Mars as Seen From Deimos



Actual Poster Size: 17" x 22"

$1.75 each

Painted by Victor Costanzo, this authentic, artistic rendition is set against a real star background as though Mars were in the constellation Taurus. Full color, varnished, suitable for framing. All posters listed here are insured and mailed in a heavy duty mailing tube.

THE ZETA RETICULI INCIDENT
Zeta Reticuli — A Rare System
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The Age of Nearby Stars

The Zeta Reticuli Incident Reprint

Size 8-1/4" x 11-1/4"

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This exciting reprint combines, in one 32 page source, articles and commentary that appeared in ASTRONOMY which documented the astronomical implications of an alleged star map seen aboard a UFO by Betty and Barney Hill. While not offering incontrovertable proof that alien visitors to Earth live on a planet circling the star Zeta Reticuli, the astronomical detective work is persuasive. Commentary is provided by scientist Carl Sagan and Steven Soter as well as Jeffrey Kretsch, Robert Scheaffer, Marjorie Fish, David Saunders and Michael Peck. Full color, illustrated throughout, varnished cover.

Milky Way in Sagittarius

Actual Poster Size: 17" x 22"

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Photograph made by Orien A. Ernest using a home built cold camera shows clusters, nebulae and star clouds in true relationship to each other and to the constellation Sagittarius' teapot asterism. Better than a star atlas of this sky region, the photograph reveals in dramatic reds, golds and blues, objects you can easily find with your naked eye or binoculars. Varnished, suitable for framing, mailed in a heavy duty mailing tube, insured.

ASTRONOMY 1976 Sky Almanac

Opened Size: 11" x 17"

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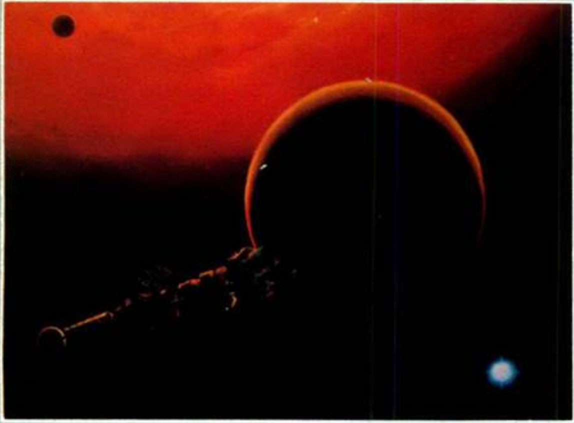
This 28 page calendar was designed exclusively as a vehicle to carry full color, varnished reproductions of some of the best art and photographs that have appeared in ASTRONOMY. Complete framing instructions are provided for the 12 full color illustrations. It also contains maps of each month's sky — useful in any year. An almanac of 1976 sky events is included along with introductory level observing projects.

Exploration of Antares Star System



Actual Poster Size: 22" x 34"

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Painted by John Clark, this imaginative rendition shows a 21st century starship exploring a scorched Earth sized planet and its moon in orbit about Antares. The red super giant star looms ominously, filling most of the sky while Antares' blue-white dwarf star companion is seen at lower right. Full color varnished, framable.

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July 1976 Vol. 4, No. 7

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Cover

The North America nebula is a fitting subject for the cover of ASTRONOMY's July issue: a tribute to the history of astronomy in America. The wide ranging subject matter of this special issue covers a time span extending from the earliest known observations made by the original inhabitants of America to the newest discoveries of recent years: quasars, pulsars and black holes. Included are discussions of the history of colonial astronomy, the important observatories, great scientists and astrophotography. The photograph on the cover is, in fact, one of the first color photos to be obtained at a major observatory. Hale Observatories photograph copyright© by California Institute of Technology and Carnegie Institution of Washington, D.C.

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PUBLISHER'S PREFACE

We could garbage up this month's Publisher's Memo with loads of nationalistic apple pie flag waving, or insult your intelligence with crass Madison Avenue marketing verbiage and barking: "After all folks, you too can have your very own set of red, white and blue bicentennial dentures!"

And humble though I be, I could attempt to reiterate or paraphrase the exciting story of astronomy's evolution in the United States. But even that might diminish the dignity of our nation's struggle to achieve "one small step for Man, a giant leap for mankind" as we begin our third century toward man's dream of worlds unseen.

Instead, with great pride we direct your attention to the contents of this issue and the commitment and hours of work the authors — five men and one woman — together with ASTRONOMY's editorial staff, have gone through during the past year and a half to bring you the "History of American Astronomy" in one concise, colorful, well-written source.

We trust you won't mind that we found it necessary to break our promise of a 96 page issue. But once we had examined all the excellent articles, paintings, photographs, other illustrations and advertising, we simply could not do justice to all this material without creating the 112 page opus you now hold. To our knowledge, this July 1976 issue of ASTRONOMY magazine is a first not merely in terms of content, but also size.

Furthermore, this issue will be exposed to more people in the United States and throughout the world than any other magazine of space and astronomy in our nation's history. Because of ASTRONOMY's advertising in SCIENTIFIC AMERICAN, NATURAL HISTORY, SMITHSONIAN and SCIENCE NEWS, and coverage of the historical content of this issue on the TODAY SHOW, promised us by the NBC television network — as well as other publicity this magazine and issue will receive — more than 25 million Americans will be exposed to ASTRONOMY and more than 200,000 people will have read the July "History of American Astronomy" issue by the end of 1976.

What does this mean for projected growth of ASTRONOMY's paid subscription circulation? With such broad public exposure, it is very difficult to determine; however, I believe with the January 1977 issue, ASTRONOMY will have between 80,000 and 100,000 paid subscribers.

Only time will tell, of course. But we want you to realize that this issue of ASTRONOMY is valuable because of its importance and impact, and that it probably represents one of the few dignified items you will find with which to remember the celebration of our nation's second century.

Incidentally, only Sky Almanac and Planet Finder are included this month to keep you abreast of what's happening in July skies. The rest of our regular departments and features will return as usual next month.

* * * * *

Special recognition is due the three authors of the six features covering the years 1620-1976. Together, they have devoted countless hours to the research and writing of these articles.

- Michael Mendillo, Ph.D. is assistant professor of astronomy at Boston University. His main research activities are in geophysical and space sciences.
- David DeVorkin is assistant professor of astronomy at Central Connecticut State College. His research interests in the history of astronomy are being pursued through the history of science department at the University of Leicester, England.
- Richard Berendzen, Ph.D. is dean of the College of Arts and Sciences at American University, Washington, D.C. Formerly an associate professor of astronomy at Boston University, Berendzen has held positions with the National Academy of Sciences.

* * * * *

Lastly, due to space limitations we were unable to provide a bibliography for suggested additional reading. You may request a copy — at no charge — by writing to Penny Oldenburger, Information Officer.

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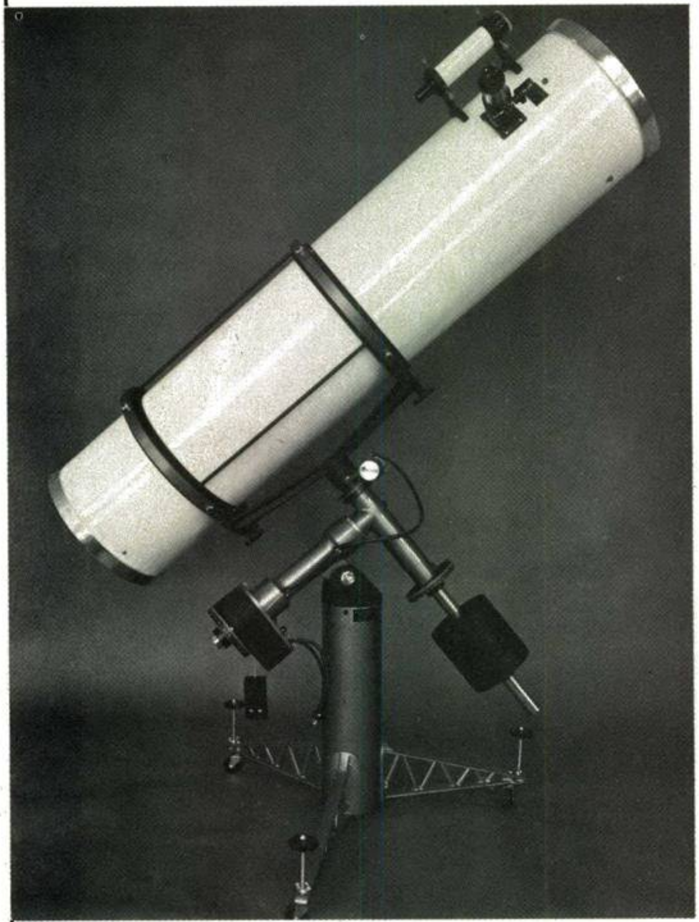

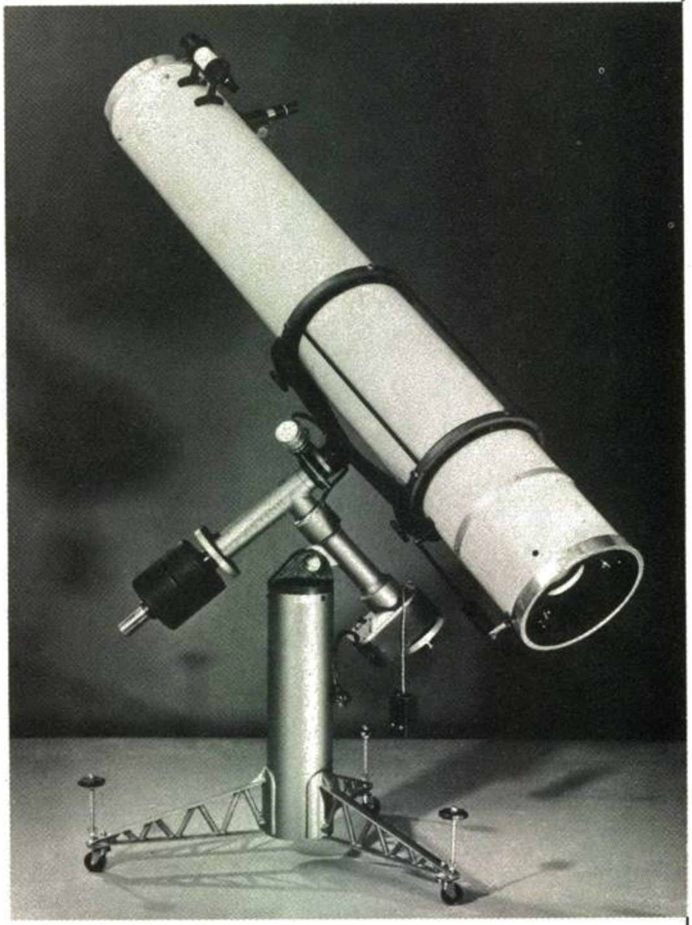

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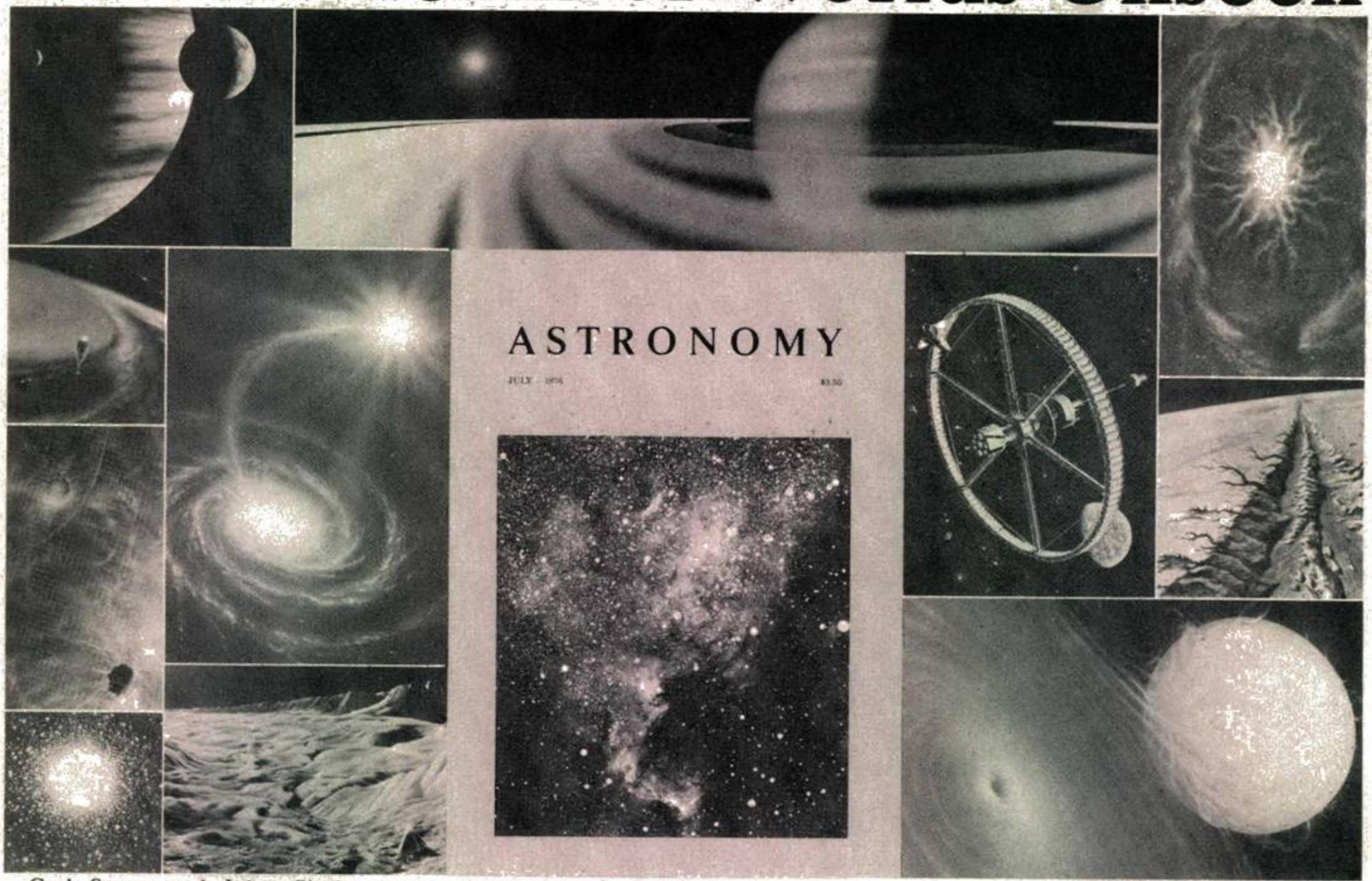

Carl Sagan and John Clark are a team.

A very unusual team indeed — scientist Sagan and artist Clark working together to open the complex vistas of the universe. Kip Thorne's black holes are mathematical concepts at best. But teamed with Adolf Schaller, artistic translation gives full color substance and form to formulae. The result? Cosmic portraits: man's dream of worlds unseen.

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Prehistoric American Astronomy (c. 1054 A.D.)

by
Von Del Chamberlain

For the earth he drew a straight line,
For the sky a bow above it;
White the space between for day-time,
Filled with little stars for night-time;
On the left a point for sunrise
On the right a point for sunset
On the top a point for noontide,
And for rain and cloudy weather
Waving lines descending from it.
From Longfellow's
Hiawatha

Interest in the sky by humans on the North American continent began neither with American scholars, nor with the colonists, nor even with European explorers. For centuries before white people arrived here, human eyes focused upward and human minds raised questions about the clouds, sun, moon, planets and stars. Explanations of astronomical phenomena were offered — explanations harmonious with the cultural concepts of the first Americans.

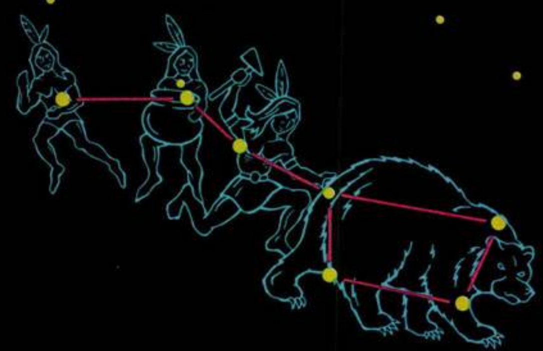
American Indians were keen observers of natural phenomena. There still exists accurate written records of their knowledge, though recently there have been indications enchorial Americans were extremely interested in the world around them. Possessing a deeply held concept of their oneness with nature, sharing the world with all other parts, they were aware of their dependence upon things both near and far including the objects and phenomena of the sky.

Indications that American Indians were interested in the sky are found throughout native American cultural and historical heritage. All across the United States, symbolic drawings and carvings on stone surfaces indicative of the sky are found. Explanations exist of celestial objects and events in the form of legends transmitted by the oral tradition from generations long gone and nearly forgotten. The stories are often fragmentary; it is likely they have been continually modified, although they probably are representative of the original narratives, now lost forever. While wandering through the ruins of Indian villages with compasses and other instruments, relationships between particular features of the silent crumbling walls, the surrounding landscape and the sky beyond are evident. It appears that many of the structures were laid out by careful astronomical observations.

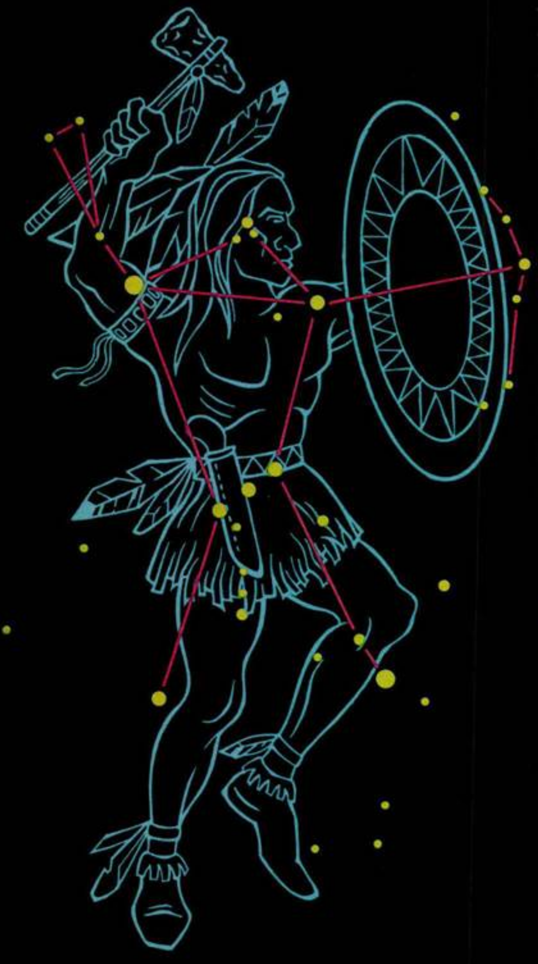
Rock art, ruins, legends, mythology, customs, beliefs and the contemporary art of American Indians all testify to the deep interest those first Americans had — and continue to have — in the sky. The art, practices, customs, beliefs and dwellings of living American Indians demonstrate that the

This native American stone "medicine wheel" was built by an unknown group of Plains Indians on the shoulder of one of the Big Horn Mountains in northern Wyoming about 200 years ago. It has been found to be aligned to the rising and setting positions of the summer solstice sun, and the rising of three bright stars of the summer sky on that longest day of the year. In the foreground, the curved line of rocks radiating from the central pile — called a cairn — points to the position where the sun rises on the first day of summer. The site has been referred to as the "Stonehenge of the West". This wheel, and other similar ones, may mark the burial sites of tribal chiefs. Photograph by Thomas Kehoe/Milwaukee Public Museum.

"Bear Hunt" (Ursa Major)



"Mighty Warrior" (Orion)



Skylore of Indigenous Americans

by

Henry J. Phillips

Original inhabitants of what is now the United States — Eskimos, North American Indians, and (in Hawaii) Polynesians — lived in close contact with nature. The elements, land, sea and sky were far more than important parts of these peoples' lives; they were life, livelihood and subsistence. The sky especially, with its varied and transient phenomena, was a vital force to indigenous American cultures, resulting in the proliferation of sky legends and mythology.

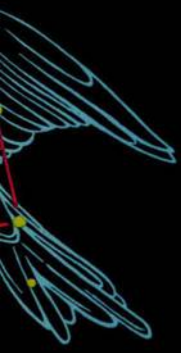
Although stories explaining the origins and existence of stars were invented, there was no great interest in dividing the sky into constellations. Only the most prominent star groups had legends associated with them.

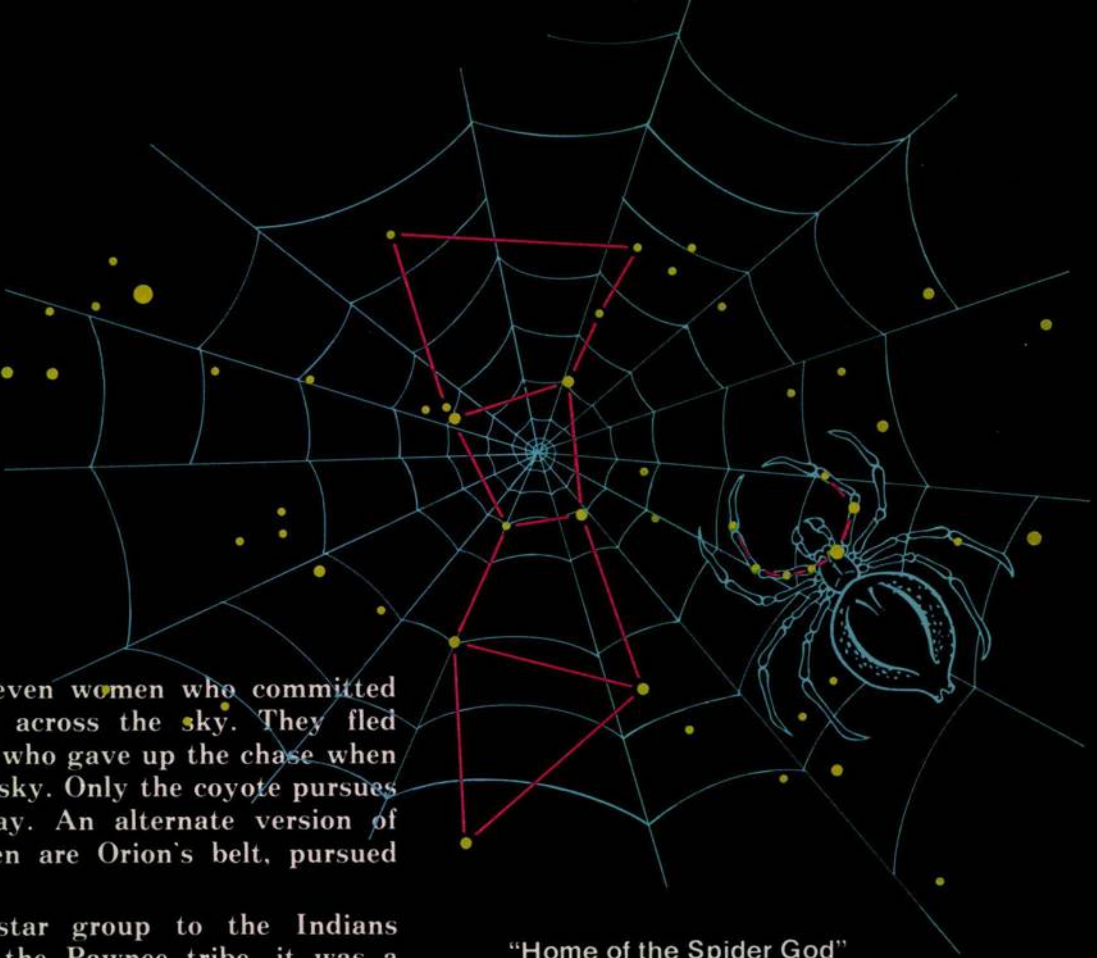
Many of these legends have the same theme: pursuer and the pursued; stories relate an endless, unsuccessful chase of one animal, person or group of persons by another. Because survival depended on the chase or hunt, coupled to the slow wheeling of the stars across the sky, such tales were natural. For example, both the Eskimos and Iroquois Indians represented Ursa Major as a bear, with the three stars in the handle of the dipper asterism representing warriors hunting the animal. Alcor, the tiny companion to Mizar (the middle star), was a dog to the Eskimos and a cooking pot to the Iroquois. The Indians further embellished the story by explaining that, when the bear was near the ground in autumn, its dripping blood turned leaves on the trees red.

In an interesting reversal of this story, the Blackfoot Indians of the plains said the seven stars of the Big Dipper were seven youths, chased into the sky by a bear! The Assinboins said the youths were impoverished, and took refuge in the sky before they starved.

Orion, of course, represented a hunter to many Indian cultures, just as it did to the Greeks, while Southwestern tribes explained he carried the sun on his back. The Pima Indians depicted Orion as a coyote

"Creator Raven" (Corvus)





chasing the Pleiades — seven women who committed crimes of cannibalism — across the sky. They fled from their irate husbands, who gave up the chase when the women escaped to the sky. Only the coyote pursues the cannibal women today. An alternate version of this story says the women are Orion's belt, pursued by Sirius.

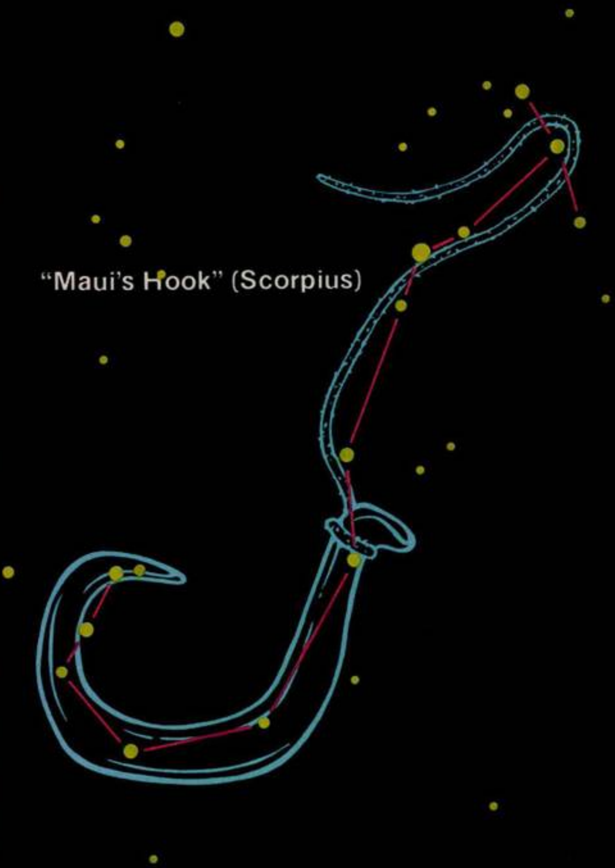
Another distinctive star group to the Indians was Corona Borealis. To the Pawnee tribe, it was a circle of chiefs — guardians of a mystic sign. But the Blackfeet called Corona the home of the Spider God. The circle of stars was the spider's body, and the brightest stars in neighboring Hercules were the first delicate strands of its web. The web grew thicker and longer as it moved east, finally reaching all the way from Earth to heaven. The web, of course, is the Milky Way.

The Indians of the Pacific Northwest tell many stories of Raven, the trickster, who eventually was identified with the constellation Corvus when European influence began making itself felt. Raven was credited with the theft of fire, the placement of the sun in the sky, and the scattering of stars across the heavens.

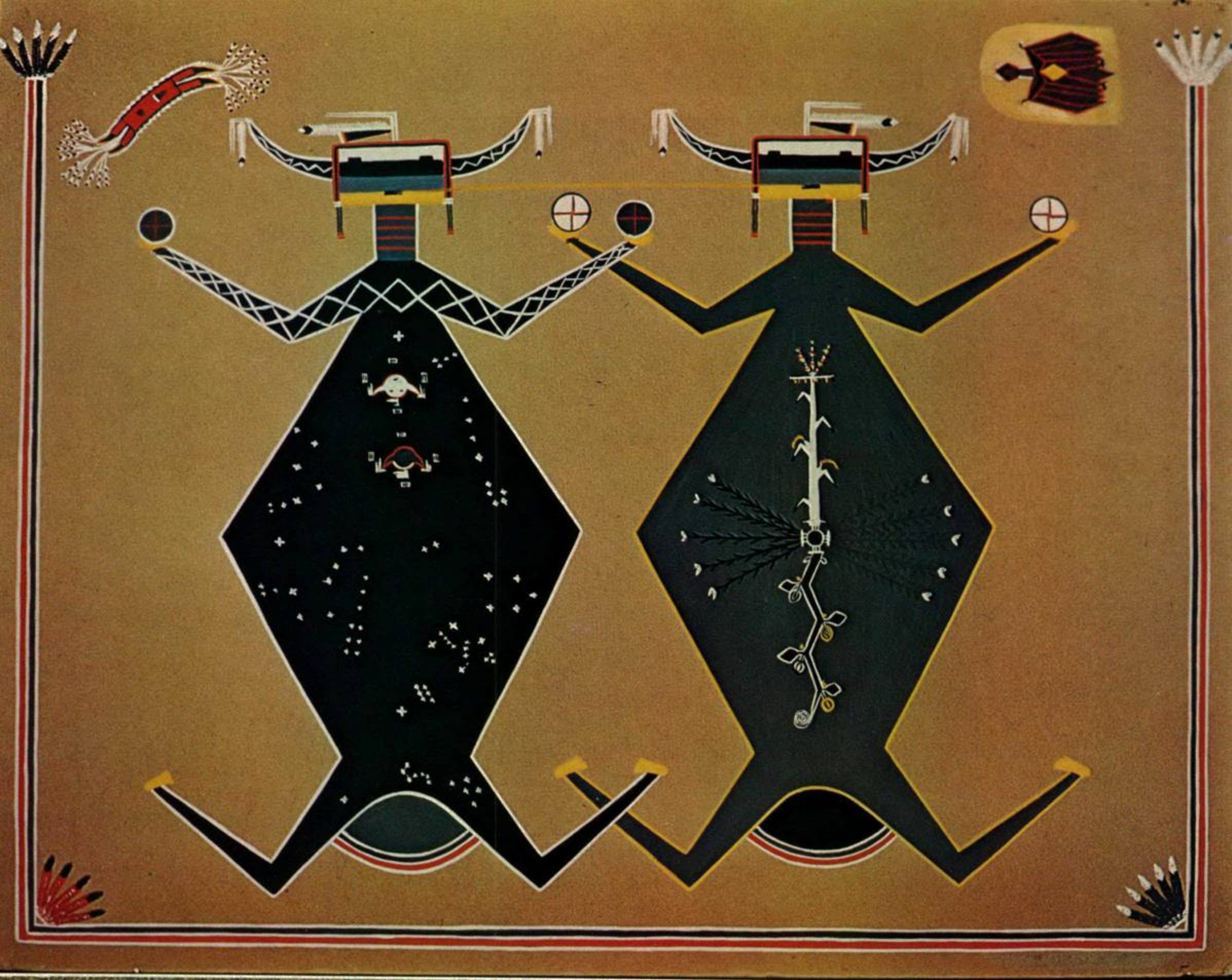
Among the Polynesians, the sea was naturally the main source of livelihood, and most mythology — including sky legends — has some connection with the sea. The constellation Scorpius, for example, is known as Maui's Hook. The god Maui fished up the land from the depths of the ocean in a story that has many versions among Polynesian cultures. To the natives of Hawaii, this feat was more or less accidental. Maui was a powerful god, but whatever his other attributes may have been, he wasn't a fisherman. This didn't stop him from trying, however, and he frequently exasperated his companions by demanding they let him accompany their fishing expeditions. On one such trip, Maui hooked the land at the bottom of the sea and began dredging it up to the surface. He warned his friends not to look back but they did, and were so amazed that they stopped rowing — whereupon the line broke, and all the land except a few bits (the islands of Hawaii) returned to the sea.

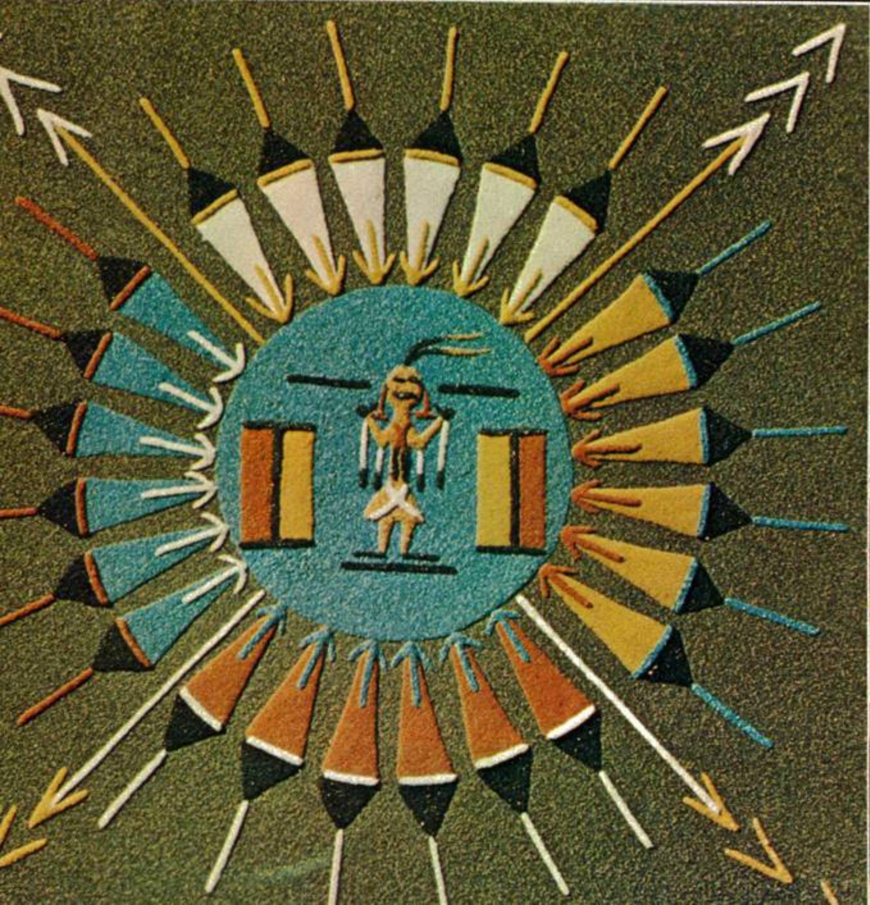
"Home of the Spider God"
(Corona Borealis/Hercules)

"Maui's Hook" (Scorpius)



Artwork by Michael Elkevizth





sky continues to play a dominant role in their way of life.

In the past few years a new research field, archeoastronomy, has developed as scholars considered relationships between archeology and astronomy. It has been demonstrated that many ancient human built structures were aligned by astronomical observations. Most attention was, until recently, centered on such edifices as the pyramids and Stonehenge. Researchers are now looking more carefully at many ruins in North America.

The American Southwest contains numerous ruins ranging from single family dwellings to small cities where thousands of people once lived. Studies suggest that many of the buildings were laid out according to observations of the rising and setting of the summer and winter solstice sun. It has also been postulated that many ceremonial *kivas* — underground or partially underground rooms — may have been designed according to observations of the rising or setting of stars especially significant to the people who used the kivas. Religious activities occurring in these places were keyed to the apparent motions of special star groupings.

Many ancient villages were built on mesa tops rather than in the shelter of valleys. Some of these "cities in the sky" still exist. One, Oraibi, is the oldest continuously occupied village in the U.S., while another, Acoma, is often referred to as "the Sky City" (both are in the southwest). People living in these sky cities were very aware of the repetitious cycles of the sun, moon, planets and stars as well as irregular or unusual events such as eclipses, comets, fireballs and bright novae.

A modern case makes us aware of how deeply embedded celestial observation is in the lives of indigenous Americans. During the planning stage of the construction of the Jemez Dam in New Mexico, government authorities requested that the people at the pueblo at Santa Ana consider moving the pueblo. After much deliberation, the pueblo fathers said they could not move it since they were unable to locate another place where the necessary observations of sky objects could be made. The features of the landscape had become their sight-lines — their cultural pathways between heaven and Earth.

Although it is difficult to evaluate the astronomical awareness of nomadic Indian groups, there is some evidence that they, too, were observers of the sky. Ethnographic and archeological evidence suggests that a highly developed star cult existed among the Pawnee Indians. Pawnee villages were grouped to represent the principal deities of the Morning Star, Evening Star, North Star, South Star (possibly Canopus?) and four other unidentified stars known as Black Star, Yellow Star, White Star and Red Star. Each village had a shrine associated with its appropriate star.

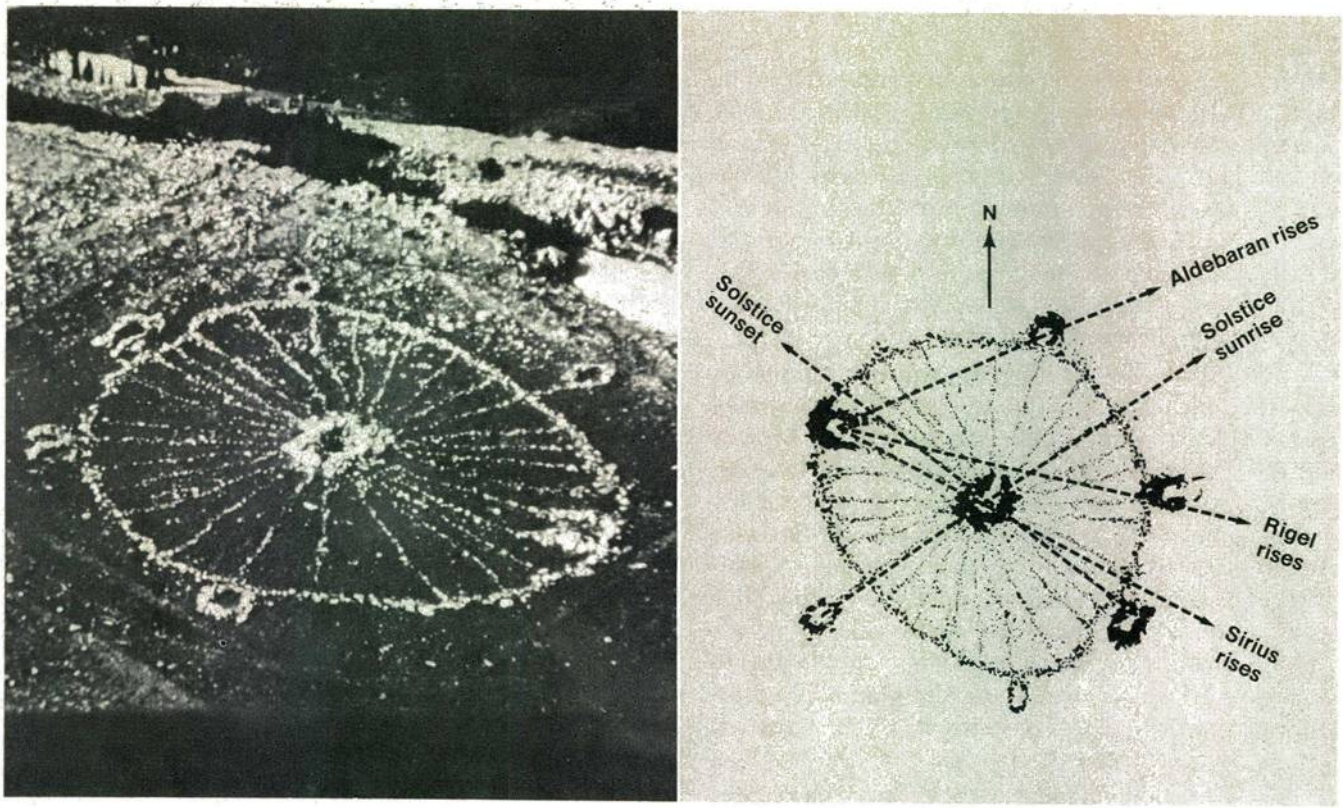
The top photo is a Navajo sandpainting of Father Sky and Mother Earth. The body of Father Sky contains the sun, moon and stars; the Milky Way is represented by zigzag lines across the figures's arms and shoulders. Life giving solar energy radiates from Mother Earth's breasts. Photograph by the Museum of Navajo Ceremonial Art. At lower left, the sun and eagle are depicted in a Navajo sandpainting. Light from the eagle's feathers surround the sun in colors of the rainbow, symbolizing the combined powers in the sun, atmosphere and water. At upper right is an elaborate petroglyph near Santa Fe, N.M. Three four-pointed stars inside the figure suggest a constellation figure. The crescent and star pictograph (lower right) were found in the Chaco Canyon National Monument. This set of symbols may depict the 1054 supernova. Photographs by Von Del Chamberlain.

The Pawnees associated these star deities with the world about them. Four of them were thought to be responsible for support of the sky dome overhead. This association of objects and ideas was reflected in the construction of the Pawnee earthlodge; the circular floor represented Earth, the domed roof-wall was symbolic of the sky, the central firepit was associated with the sun, and four large posts supporting the roof represented the star-gods of the four leading villages. It is also thought that the earthlodge's doorway, which faced east to allow the first rays of the morning sun to fall upon the altar, and the smokehole directly above the firepit, both served as openings through which the positions of the stars could be observed, pacing the ceremonies. Council circles of another tribal nation, the Wichitas, are aligned with each other along summer and winter solstice sunrise and sunset directions.

High in the mountains near Sheridan, Wyo. is a large wheel-like arrangement of stones known as "the Big Horn Medicine Wheel". Its exact function is unknown to us, although many Plains Indians made pilgrimages to it. John A. Eddy, an astronomer with the National Center for Atmospheric Research, has found that the feature reveals impressive astronomical alignments to the summer solstice sunrise and the rise of the three brightest stars of summer dawn: Aldebaran, Rigel and Sirius.

Many Indian concepts were shaped by the continual changes of the sky. Turquoise, the Indian gemstone, is linked with the sky since it possesses all the blue sky shades ranging from the light blue of morning to the cerulean of midday and the lapis lazuli of the approaching storm. In addition, a piece of turquoise may change or fade in color, just as the sky does.

Navajo mythology explains that the sun and moon were formed from large pieces of crystal and placed in the sky. After the two greater lights were created, the gods continued their work using leftover chips of crystal to make the stars. These were being placed in the sky in carefully planned patterns when the mythological figure Coyote came along and wanted to help. Each of the stars had been given a spark of fire and a path to follow, except for the polestar, meant to remain stationary as a guide to travelers. In an impulsive moment, when the other gods weren't looking, Coyote seized the blanket where the star chips were lying and flipped the re-



An aerial photograph of the Big Horn Medicine Wheel in northern Wyoming (left) shows the wheel-like layout of this American Indian site. Twenty-eight unevenly spaced spokes radiate from the central cairn or hub and extend to the outer irregular circle of rocks that mark the rim of the wheel. Five small cairns were spaced at various positions along the perimeter of the wheel, while a sixth cairn lies slightly beyond the rim. The wheel is about 80 feet in diameter. The drawing (right) illustrates the celestial alignments of the wheel. Poles may have been placed vertically in pairs of cairns to allow observers to sight certain celestial phenomena. No astronomical alignments have been found for several pairs of cairns. The word "medicine" was used by American Indians to mean "magic" or "supernatural". Photograph and drawing by John A. Eddy.

maining stars into the sky. This is why, the Navajos said, a few nice star patterns are interspersed among the random scattering of those carelessly distributed by Coyote.

The positions of the stars are attributed to Coyote by some other Indian nations. A Papagos legend suggests that Coyote, while wandering across the sky, came upon a house. Being hungry, he went inside to look for food. He found some cornmeal (a staple food of the Papagos) and was about to eat it when he was startled by someone shouting "Shoo! Shoo!" Away he ran with the sack of meal held in his teeth. As he fled across the sky, the cornmeal sprinkled from the partially open bag. We can look up there now and see the particles of meal transformed into glistening stars. Coyote's path is clearly marked by the Milky Way.

The Raven was also connected with the creation of the heavenly bodies. Pacific Northwest Indians told the following legend:

Very, very long ago the world was cold, dark and lacked fresh water. The sky was empty. Selfish Gray Eagle kept the sun, moon, stars and fresh water hanging in his lodge where the fire burned brightly. His beautiful daughter lived with him.

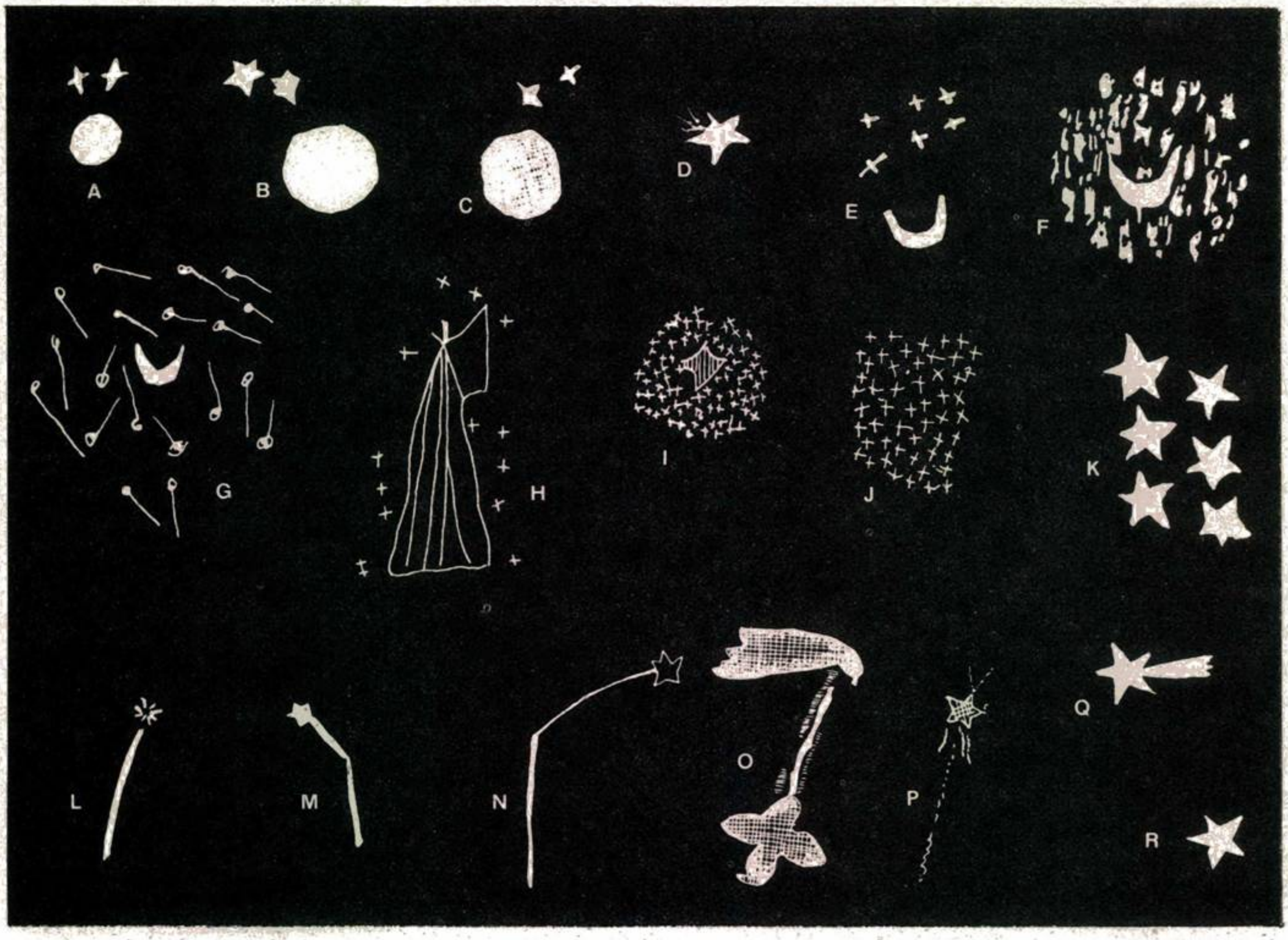
In those times Raven was a handsome young man. He fell in love with Gray Eagle's daughter and to be near her he changed himself into a snow white bird. In this form, he found favor with the girl who invited him to her father's lodge.

Once inside he quickly noticed the sun, moon, stars and fresh water. Aware of their importance, he formed a plan and waited for the right opportunity. When no one was looking he quickly seized the great and small lights, the water and a firebrand and flew up through the smokehole.

Outside he flew up high into the sky and placed the sun there to light the world. He could now see to great distances and flew to a faraway island and waited for the sun to set. Then he placed the moon in the sky and carefully hung the stars in various places. By this new light he flew back over the land and selected just the right place. There he dropped the water which landed on the ground, becoming the source of all the fresh water lakes and streams in the world.

Holding the firebrand in his bill, he flew on through the night. The smoke from the fire blew back across his snowy feathers, decreasing their brilliance. As he went on his feathers became darker and darker and eventually they were black. The fire continued to burn, consuming the brand. Finally Raven's bill started burning and he dropped the fire which streamed through the sky, falling on rocks, entering them.

Raven remained a black bird. The sun still



The first step in the development of writing among Plains Indians was the annual recording of selected celestial events — represented by pictographic symbols — on leather and cloth. Known as "winter counts", Plains Indians used them to record the sequence of years in calendar form and devices to recall important events. The above drawings are representations of pictographs made by Dakota Indians at various times during the 19th and 20th centuries. A is said to represent a lunar eclipse, while B and C portray the total solar eclipse of Aug. 7, 1869. The morning rise of Venus may be represented by D. The Leonid meteor shower of 1833 is shown in E through K, while fireballs during the winter of 1821-22 and 1903 are shown in pictographs L through R. Drawings by Zenon Billeadeaux.

illuminates Earth, warming it and producing the seasons. The moon waxes and wanes and the stars are still in the sky. Fresh water flows on the warm Earth. And to this very day, if one knows how to properly select stones and strike them together, fire drops out of them.

Like myths from other parts of the world, the story of Raven as creator indicates the belief that fire came from the sky. This is easily understood since lightning, meteors and fireballs are all fierce events, appearing to streak from sky to Earth just as the firebrand did. Likewise, the drama of fresh water dropping from the sky is often repeated as rain condenses from the moist air and falls, sometimes in torrents, to replenish the streams and lakes. The idea of the sun, moon and stars being placed in the sky by a creation figure is worldwide.

Navajo symbolism included certain constellations representing all the forms of life mentioned in their old legends, as well as a particular set of constellations whose individual members were each associated with a law for people on Earth. This tribal nation believed the rules for living were written in the stars.

Indian legends were often ways to explain and describe changes in the surrounding world, which included the sky. Changes in atmospheric events — together with the cycles of the sun, moon, planets and stars — form the basis of many Indian legends, while other legends relate to more unusual occurrences: eclipses of the sun and moon, occultations of planets and bright stars, meteors and meteor showers, rainbows and halos. The occasional nova and the very rare supernova may have found their way into autochthonous American legends. An example of legendary recall of celestial events — here the apparent occurrence of the implied impact of a meteorite or fireball — is quoted from **Indian Legends From the Northern Rockies:**

The world was very young when this story took place. It was before our grandfathers' grandfathers' days, but there were people who saw these things. They saw a burning star race through the air and jump into the lake now called Flathead Lake.

One darkness, when the people were in their *tipis, they heard a star shrieking in terrible pain. Going outside to see why it was making such crying, they saw that it was burning up. The light of the flames brightened all the sky and the land as if it were day instead of night.*

The people saw Burning Star running swiftly down to the lake and jump into the deep water near Wild Horse Island. Immediately a thick cloud rose from the water and hung over the lake.

Our people were very much frightened and would not go near the shore. "The Water Mystery," they said, "has reached out with its strong power, has pulled the Star from Skyland, and has taken it into the lake. If we go near it, it will pull us in also."

But the Mystery People of the Lake, the Canoe People, said, "No, it is not the Water Mystery which pulled Star, for water mysteries have no influence over sky and land mysteries. Foolish Salish, do you not know this? We, too, saw Star burning in the sky, and we heard its cry of pain as it jumped into the lake to put out its flames. Not being made of fear, we paddled our canoes close. The water was warm, and many, many cooked fish floated on the waves."

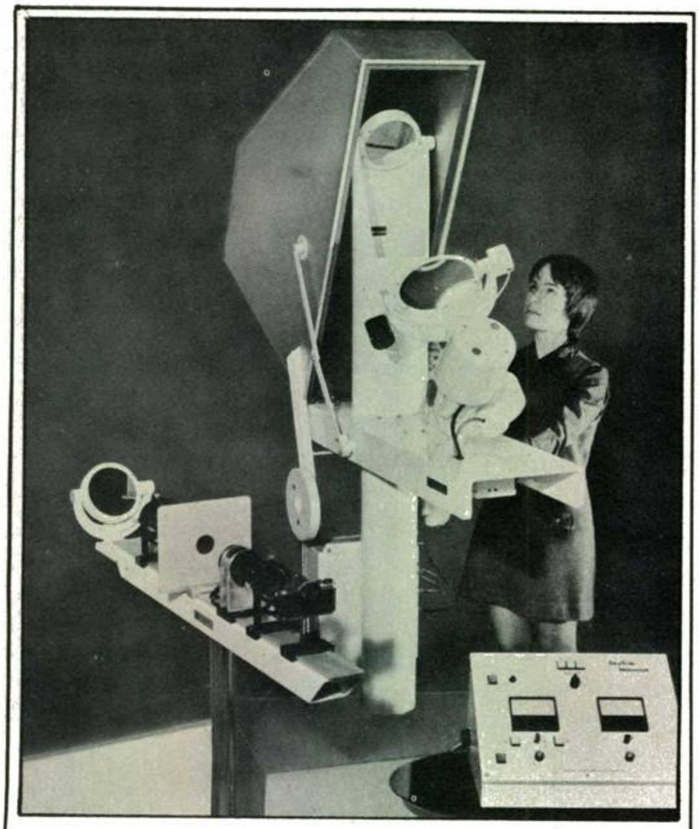
Tribes that lived many sleeps away also saw Burning Star and its light. Only the Mystery People of the Lake were not afraid. So our fathers sometimes called them "the Fool People." Perhaps they meant "the fool-hardy people."

From **Indian Legends From the Northern Rockies** by Ella E. Clark. Copyright© 1966 by University of Oklahoma Press.

American Indian art includes a variety of sky symbols. While the sun is probably the most popular of all symbols in Indian art, clouds, lightning and rain symbols are also common. The crescent (moon) is less common, but examples continue to turn up as interest in astronomical symbols increases. Star symbols exist in several forms: dots, circles, crosses, triangles and multirayed points. The four-pointed star and the simple cross are the most common star depictions. Other symbols include the sky bar (representing the sky itself), the rainbow, comets, meteors and fireballs.

The earliest examples of sky art appear in symbols painted (pictographs) or inscribed (petroglyphs) on the sides of cliffs, cave walls, boulders and the walls of manmade structures. The symbols are also exhibited on pottery, woven into rugs, laid out in drypaintings (sandpaintings) and included in indigenous crafts — especially in bead and silver handiwork. Sky symbols are often incorporated in the design of Pueblo Kachina masks and dolls.

One other interesting symbolic art form is the "winter count" calendar kept by Plains Indians. A method of remembering the years as they passed (one symbol representing each year), these picto-



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graphic histories have included the total solar eclipse of Aug. 7, 1869, the Leonid meteor shower of 1833, and two bright fireballs in 1821-22 and 1903.

Navajo drypaintings often contain sky symbols; rainbow and light bars, sun and moon depictions or representations of clouds, rain and lightning appear in the majority. These paintings always illustrate the sacred colors associated with the cardinal points (north, east, west and south) and the sky. White is the color of both the east and the first rays of light after the darkness of night. Blue represents the south and midday, as well as the entire dome of the sky. Yellow stands for the west, as well as symbolizing pollen, well-being, peace of mind, the late afternoon sunshine and the evening of life. Black is the color of the north and of night. It appears as a layer of black sand decorated with white stars, the sun and moon, and is outlined with white morning light.

Modern Indian art tends to contain the same sky symbols found in rock art, old kiva art and pottery designs. Perhaps nothing is more representative of the Indian identity with nature than the sky symbols contained in virtually every aspect of native American life.

Although the American Indians did not possess the cultural factors which lead to scientific exploration, they searched for and found a harmony existing between themselves and their surroundings. The deep appreciation they had for the sun and stars might wisely be blended with the understanding that comes from experimentation, measurement, theory and observation. Some combination of the natural primal wonder of our dependent existence in the universe and our increased understanding of the sciences of the universe could establish the environmental value system the American Indians recognized as so important. We might do well to emulate some of the values of the early inhabitants of the North American continent as we look forward to our tercentenary in another 100 years.

Oh our Mother the Earth, oh our Father the Sky
Your children are we, and with tired backs
We bring you the gifts that you love.
Then weave for us a garment of brightness;
May the wrap be the white light of morning,
May the fringes be the falling rain,
May the border be the standing rainbow.
Thus weave for us a garment of brightness
That we may walk fittingly where grass is green,
Oh our Mother the Earth, oh our Father the Sky!

From **Four Winds, Poems From Indian Rituals,** collected by Gene Meany Hodge, published 1972. Reprinted, permission of the Sunstone Press, Santa Fe.

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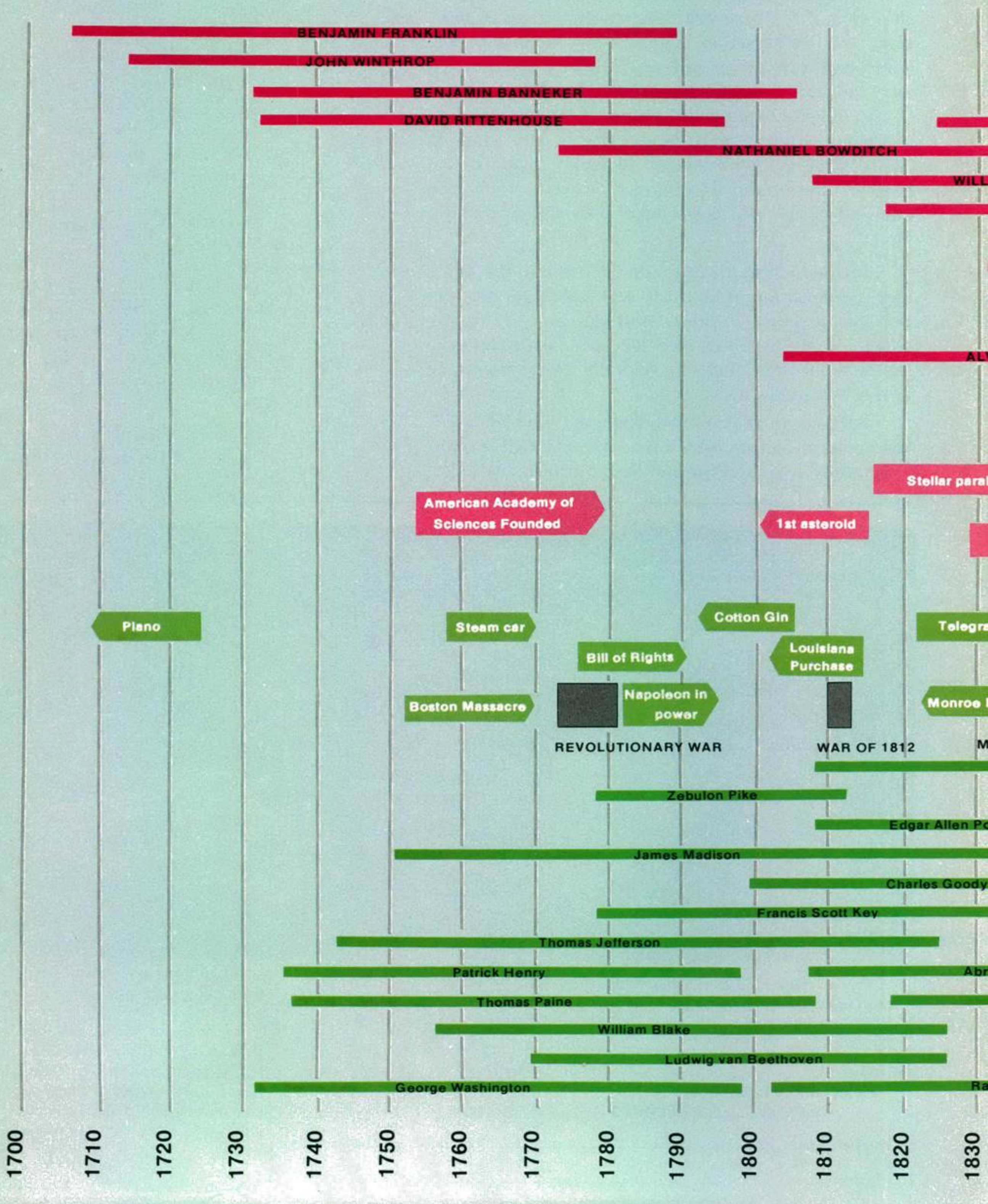
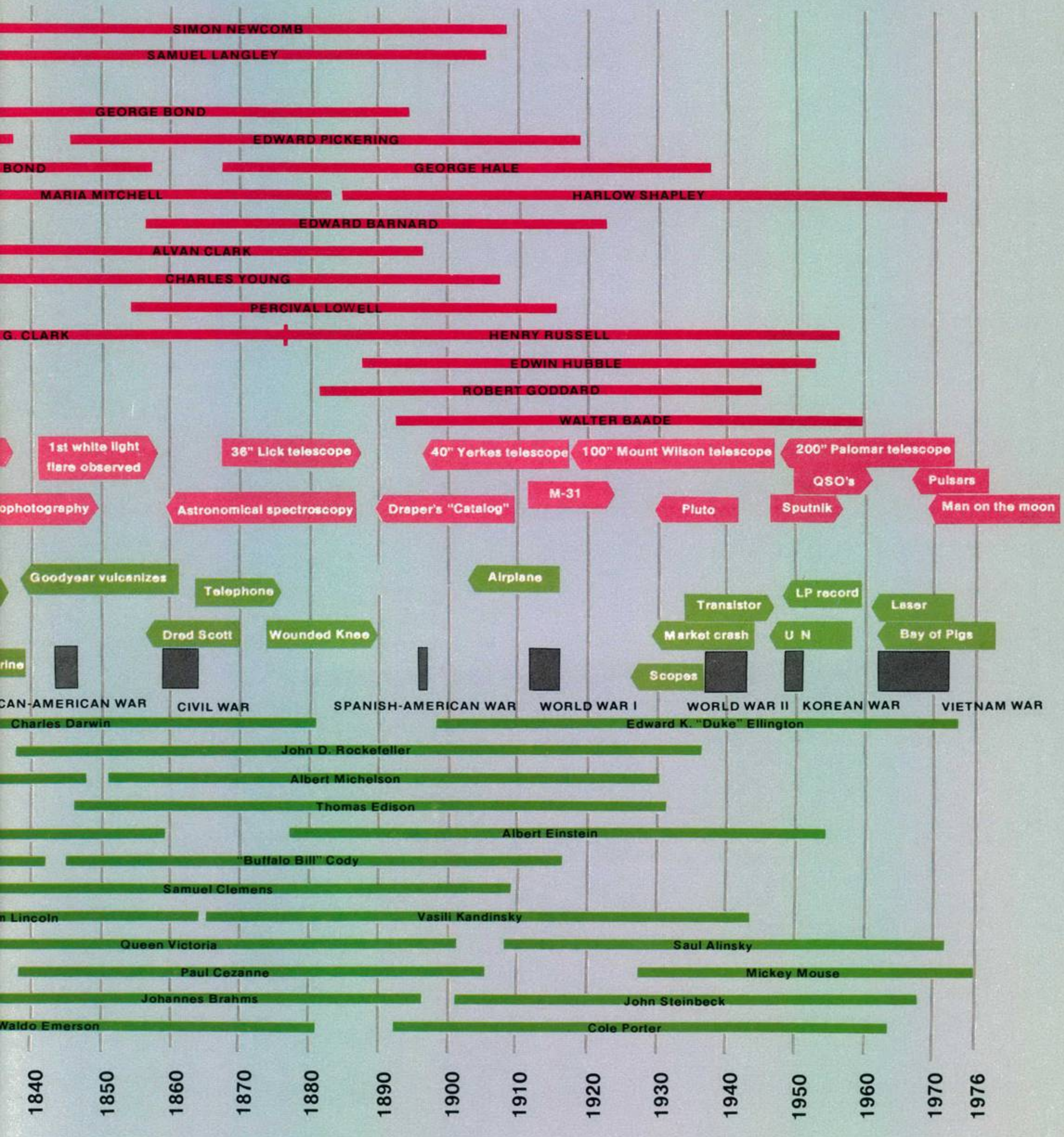
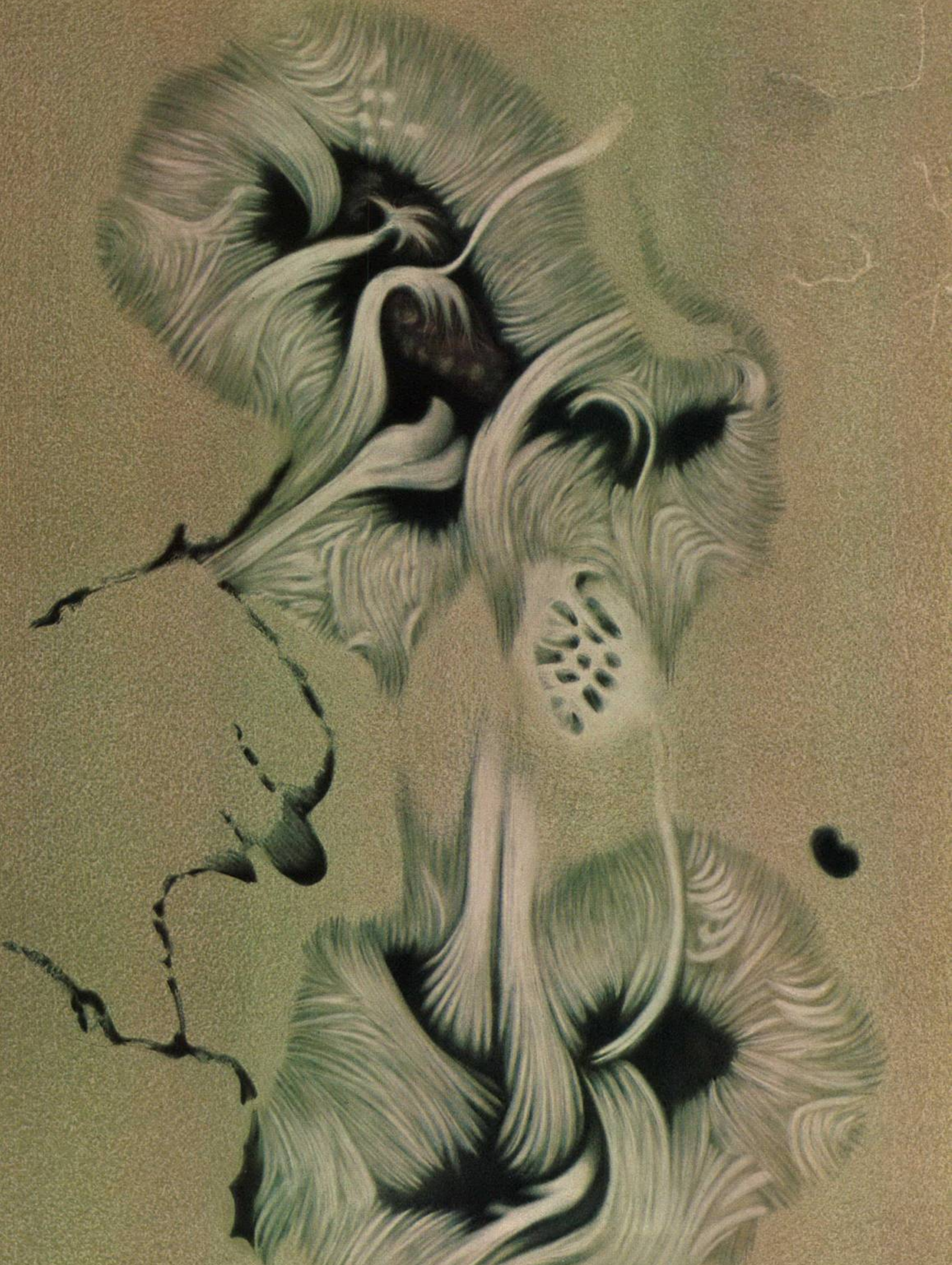
History of American Astronomy



— A Chronological Perspective —

by Michael Mendillo, David DeVorkin, Richard Berendzen





Comets and Transits: 1620-1776

Long before America took shape as a nation, Western style astronomy began in the first British settlements in New England. American astronomy actually started only about 16 years after the Mayflower Compact, with the founding of Harvard College in 1636. While Galileo was suffering the anxieties of house arrest in the Old World, the first generation of American college students and graduates in the New World were learning Ptolemaic cosmology, the astronomy of the ancients.

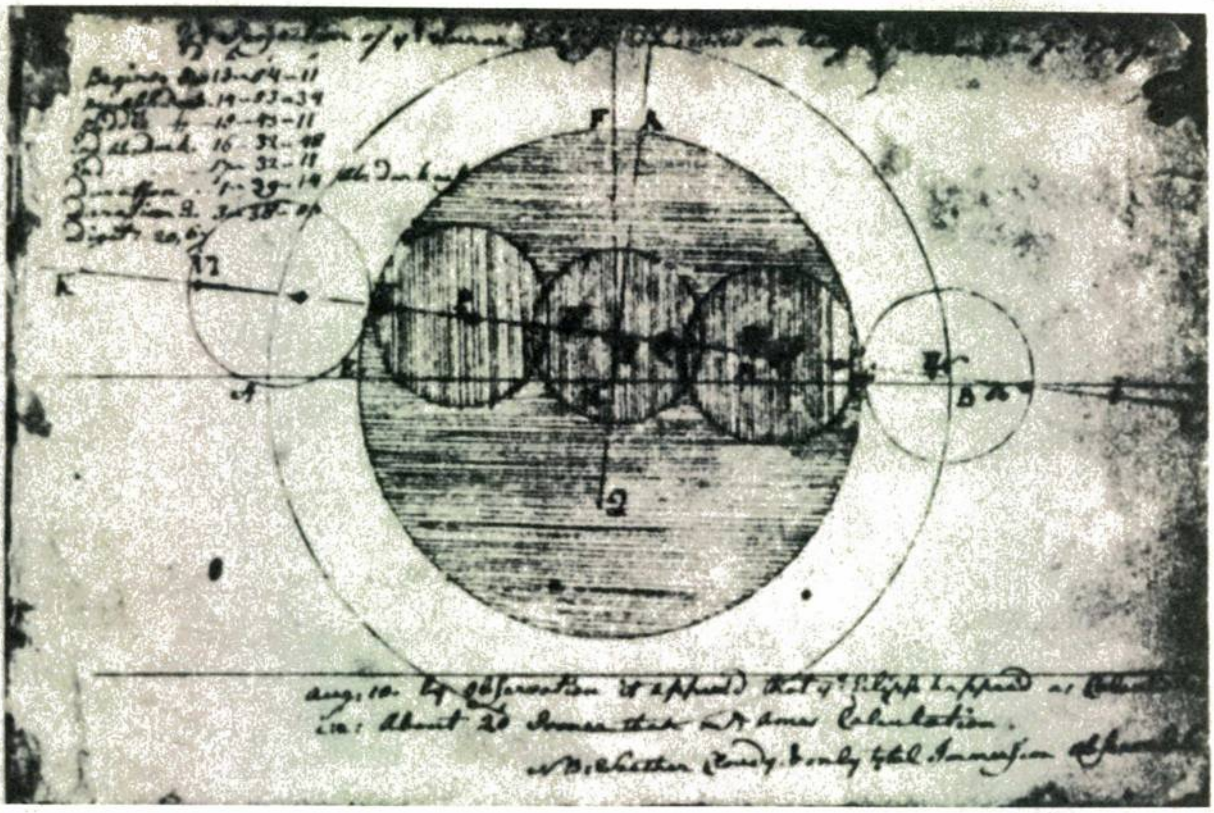
The early Americans may have been uniquely predisposed to embrace both the substance and spirit of the revolutionary new astronomy of Copernicus and Kepler. Perhaps it was simply the adventuresome spirit of a people accustomed to the ordeal of breaking ties with the past that led to a quick acceptance of Copernican astronomy. In any event, by 1659 the Copernican scheme was being formally taught at Harvard.

John Winthrop Jr., governor of Connecticut, brought America's first notable telescope to the New World in 1663. It was described only as "3 foote and a halfe with a concave ey-glass"; the 3-1/2 feet referred to the overall length of the tube. On a summer night in August 1664, Winthrop observed what he thought was a fifth moon of Jupiter. Perhaps caution as a politician — more than as a scientist — made him wait for further evidence before officially reporting it to the British scientific community. Whatever he saw, though, could not have been the fifth satellite of Jupiter; the discovery of "Jupiter V" had to wait over 200 years.

In the years preceding the American Revolution, much astronomical observation was concentrated on the sun and moon, as these objects were close to Earth and easiest to observe. This rendering of a sunspot group by E.L. Trouvelot, although not drawn until a century after the Revolution, exemplifies the most important work carried out during the years when America was still under British rule. Photograph courtesy of Fairfield County Astronomical Society.

As is often the case today, politics and administration leave little time for the practice of astronomy. So, in 1672, Gov. Winthrop presented the telescope to Harvard where it might be put to more use. In 1680, Thomas Brattle, natural philosophy lecturer at Harvard, used the Winthrop telescope to observe "Newton's Comet" (the great comet of that year) and sent the results to John Flamsteed, Britain's first Astronomer Royal and Director of the Royal Greenwich Observatory. Flamsteed, in turn, forwarded the observations to Sir Isaac Newton, the great English natural philosopher, who incorporated them into his **Philosophiae Naturalis Principia Mathematica** (Mathematical Principles of Natural Philosophy), dutifully acknowledging their source as being from "the observer in New England". With only *one* practicing astronomer and *one* telescope in all of the northern colonies, Newton apparently didn't worry about omitting mention of Brattle by name. Perhaps for that reason, Brattle's name is today best associated not with astronomy, but with the Brattle Theatre on Brattle St. in Cambridge, Mass.

During its 92 year history, the Winthrop telescope had many other distinguished "guest" observers, including the remarkable Increase Mather



The drawing above, made by Prof. John Winthrop of Harvard (see biography, page 30), is a projection of the lunar eclipse of Aug. 10, 1747 for the meridian of Cambridge, Mass. The model for similar drawings produced today, the projection depicts the path of the moon through Earth's shadow. Photograph courtesy of Harvard University Archives. Part of the cover of Nathaniel Ames' *Almanack* for the year 1761 is reproduced at right, showing the author's prediction of how that year's transit of Venus would look — as a mole moving across the face of the sun! Published in Boston, the original price for a dozen dopies was two shillings, two pence. Photograph courtesy of the American Antiquarian Society.

and his precocious son, Cotton. Both observed Halley's comet in 1682, preached and wrote extensively about this "portentous" object, freely intermingling Newtonian and Puritan concepts as occasions warranted. The Winthrop telescope came to an abrupt end on the night of Jan. 24, 1764, when a catastrophic fire ravaged Harvard Hall, destroying nearly all the scientific books and apparatus it contained.

The only telescope to survive the fire was one that Thomas Hancock, uncle of the patriot John Hancock, presented to Harvard in 1761. That same year, using this 3 inch aperture, 14 inch focal length reflector, a Harvard professor named John Winthrop (not to be confused with the former Connecticut governor) observed a rare transit of the planet Venus across the disk of the sun, from St. John's in Newfoundland, Canada. This represented the first publicly funded, college sponsored, scientific expedition made from America.

From the time Yale University was founded in 1701 through 1718, Samuel Johnson was the only full time instructor. His legacy to Yale included the introduction of "textbook astronomy" into the natural philosophy curriculum. Thomas Clap, president of the university from 1739 to 1766, added some experimental expertise to the Yale tradition through his observations of the great meteor of November 1742, and his observations the following October of a transit of Mercury. In the early 1740s, he designed and constructed an orrery (mechanical solar system model) that included parabolic wire paths for the "unexpected" comet of 1743, as well as for the much-anticipated return of Halley's comet in 1758. Clap is perhaps best remembered in print for his theories of comets and meteors; his sermon condemning the use of artificial light as dangerous to Christian morals should be graciously overlooked.

Yankee ingenuity manifested itself during this period in a preoccupation with the precision and beauty of the predictable Newtonian universe. The name of David Rittenhouse, despite his competence in various areas of physics, astronomy and mathematics, is today most often associated with orreries — named after Britain's Earl of Orrery, who first commissioned one. The triumphs of Newton had been so great that clock driven gears upon gears seemed the ideal way to demonstrate modern astronomy's perfect reduction of the mysterious ways of the heavens to a well-oiled machine.

In 1767, Rittenhouse began construction on his first and most famous orrery. It displayed the relative positions of the planets with an accuracy of less than one degree over a period of 5,000 years! His biographer, Brook Hindle, points out that in addition to being a teaching aid, such orreries "served as monuments to the faith of the Enlight-

AMES 1761.

An Aſtronomical DIARY, or an

ALMANACK

For the Year of our Lord CHRIST,

17 61.

The Year after Biſſextile or Leap-Year.

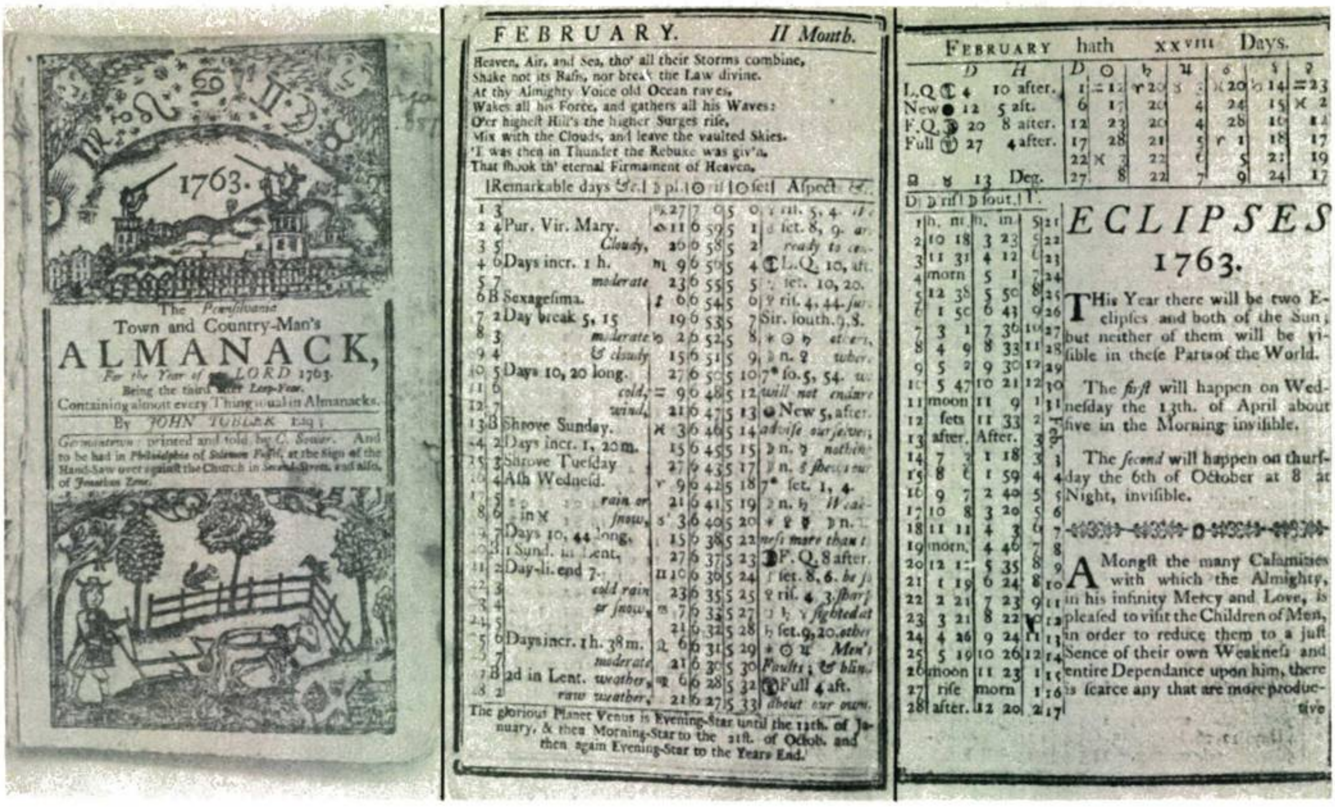
In the 34th Year of the Reign of King *GEORGE* II.

Containing, Eclipſes, Sun & Moon's Riſing & Setting, Aſpects, Lunations, Spring-Tides, Judgment of the Weather, Courts, Feaſts & Faſts of the Church, Quakers yearly Meetings.— Equation Table, Tables of Coin and Intereſt, the Roads, and beſt Stages from Boſton to Rhode-Iſland, Connecticut, New-York, Eaſtern Road, &c. On the Small-Pox, &c, &c.

Calculated for the Meridian of Boſton *in* New-England, *Lat.* 42 *Degrees* 25 *Min. North.*

BY NATHANIEL AMES.

GREAT ALEXANDER, who the World had won,
Sat down and wept when all his Work was done.
AMHERST with Glory triumphs o'er his Foes,
And reſts for want of Countries to oppoſe.
CANADA conquer'd! Can the News be true!
Inſpir'd by Heav'n what cannot *Britons* do.
The News with Haſte to liſtning Nations tell,
How *Canada*, like ancient *Carthage*, fell.



The Pennſilvania
Town and Country-Man's
ALMANACK,
For the Year of our LORD 1763.
Being the third after Leap-Year.
Containing almoſt every Thing uſual in Almanacks.
By JOHN TOBLER Esq;
Germantown: printed and ſold by C. Sower. And to be had in Philadelphia of Solomon Fuſſel, at the Sign of the Hand-Saw over againſt the Church in Second-Street, and alſo, of Jonathan Zane.

FEBRUARY. *II Month.*

Heaven, Air, and Sea, tho' all their Storms combine,
Shake not its Baſis, nor break the Law divine.
At thy Almighty Voice old Ocean raves,
Wakes all his Force, and gathers all his Waves:
O'er higheſt Hill's the higher Surges riſe,
Mix with the Clouds, and leave the vaulted Skies.
'T was then in Thunder the Rebuke was giv'n,
That ſhook th' eternal Firmament of Heaven.

The glorious Planet Venus is Evening-Star until the 12th. of January, & then Morning-Star to the 21ſt. of Octob. and then again Evening-Star to the Years End.

ECLIPSES
1763.

THis Year there will be two Eclipſes and both of the Sun; but neither of them will be viſible in theſe Parts of the World.

The *firſt* will happen on Wedneſday the 13th. of April about five in the Morning inviſible.

The *ſecond* will happen on thurſday the 6th of October at 8 at Night, inviſible.

* * *

AMongſt the many Calamities with which the Almighty, in his infinity Mercy and Love, is pleaſed to viſit the Children of Men, in order to reduce them to a juſt Sence of their own Weakneſs and entire Dependance upon him, there is ſcarce any that are more productive

The 18th century almanac filled many valuable functions; the three pages reproduced above from The *Pennsilvania Town and Country-Man's Almanack* include such information as eclipse dates and times of sunrise and sunset. Photographs courtesy of The Library Company of Philadelphia. Two drawings of the moon by E.L. Trouvelot (opposite, top) show a lunar eclipse and detail around Mare Humorum. Photographs courtesy of Fairfield County Astronomical Society. Three instruments made by David Rittenhouse, colonial America's most prolific manufacturer of optical instruments, are pictured here (opposite, bottom). Shown are two telescopes and a special instrument for transit observations. Photographs courtesy of the American Philosophical Society.

enment in the reasonableness of the world." Thus, Hindle says the precision of Rittenhouse's was regarded as "symbolic of the precision both of God's universe and of man's science."

While Rittenhouse worked on his orrery, Harvard purchased one from the well-known London instrument maker, Benjamin Martin. Rittenhouse determined to construct his orrery more exactly than Martin's so that it would not only "instruct the ignorant" but also "astonish the skillful". And, of course, he succeeded admirably in his goal.

The Transit of 1769

Transits of the inner planets across the sun were of great importance during the 18th century, since the size of the "Keplerian Solar System" was known only on a relative basis. Careful transit observations were badly needed in order to determine the actual distance from Earth to the sun and thereby calibrate the distance scale of the solar system.

It is little wonder, therefore, that the most eagerly awaited astronomical event of the 18th century was the June 3, 1769 transit of Venus — especially since the next transit wouldn't occur until 1874. By a stroke of celestial luck, the infant American colonies had the opportunity to make a significant contribution to astronomical knowledge. Britain's fifth Astronomer Royal, Nevil Maskelyne, calculated that the best location for viewing both first and last contacts of the transit was near Lake Superior, but the event was visible from within all of the settled colonies.

Observations of the 1769 transit of Venus marked the high point of American astronomy prior to the Revolution. Up until this event, astronomical pursuits by colonists had mainly been of the descriptive sort, such as observing eclipses, comets, meteors, auroral displays and sunspots. Any calculations made with the obtained data were usually aimed at determining the observer's longitude, a difficult measurement in the 17th and 18th centuries. These tedious calculations, as well as those used for predictions of celestial events for the popular domestic almanacs, required considerable astronomical sophistication. To the international astronomical community, however, the mere application of such tried and true techniques was of little interest. But now, in 1769, the chance occurred to take part in an experiement of definite significance — measuring the size of the solar system!

To encourage American participation in the needed observations, Nevil Maskelyne asked Benjamin Franklin for help in mobilizing the colonists. Although Franklin was a personal friend of Prof.

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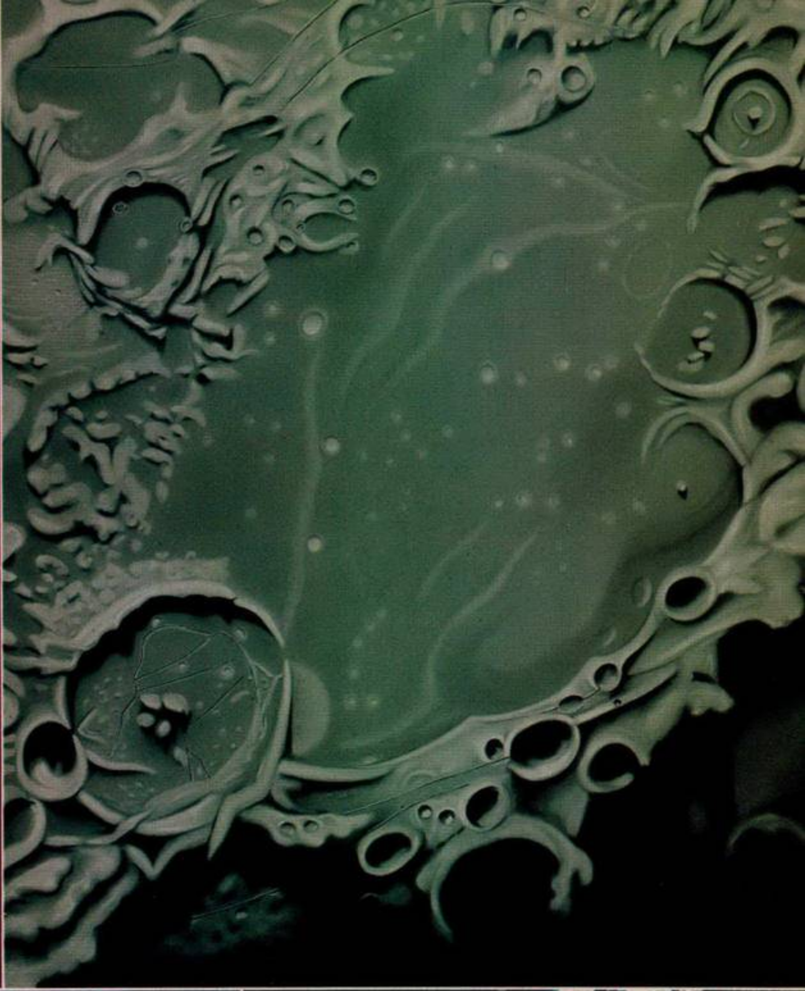
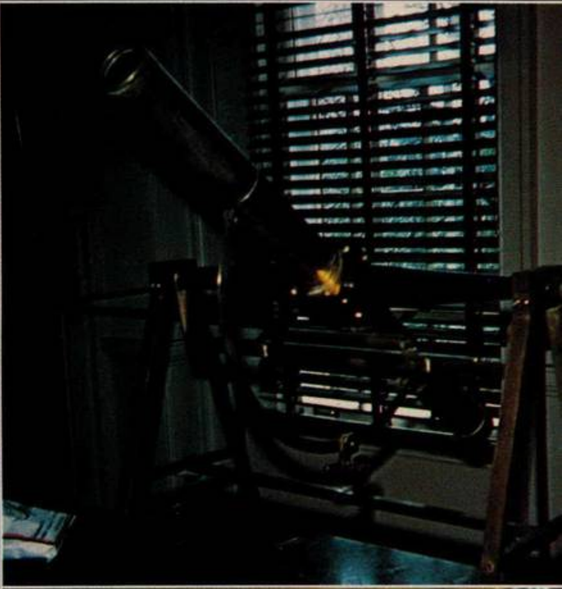
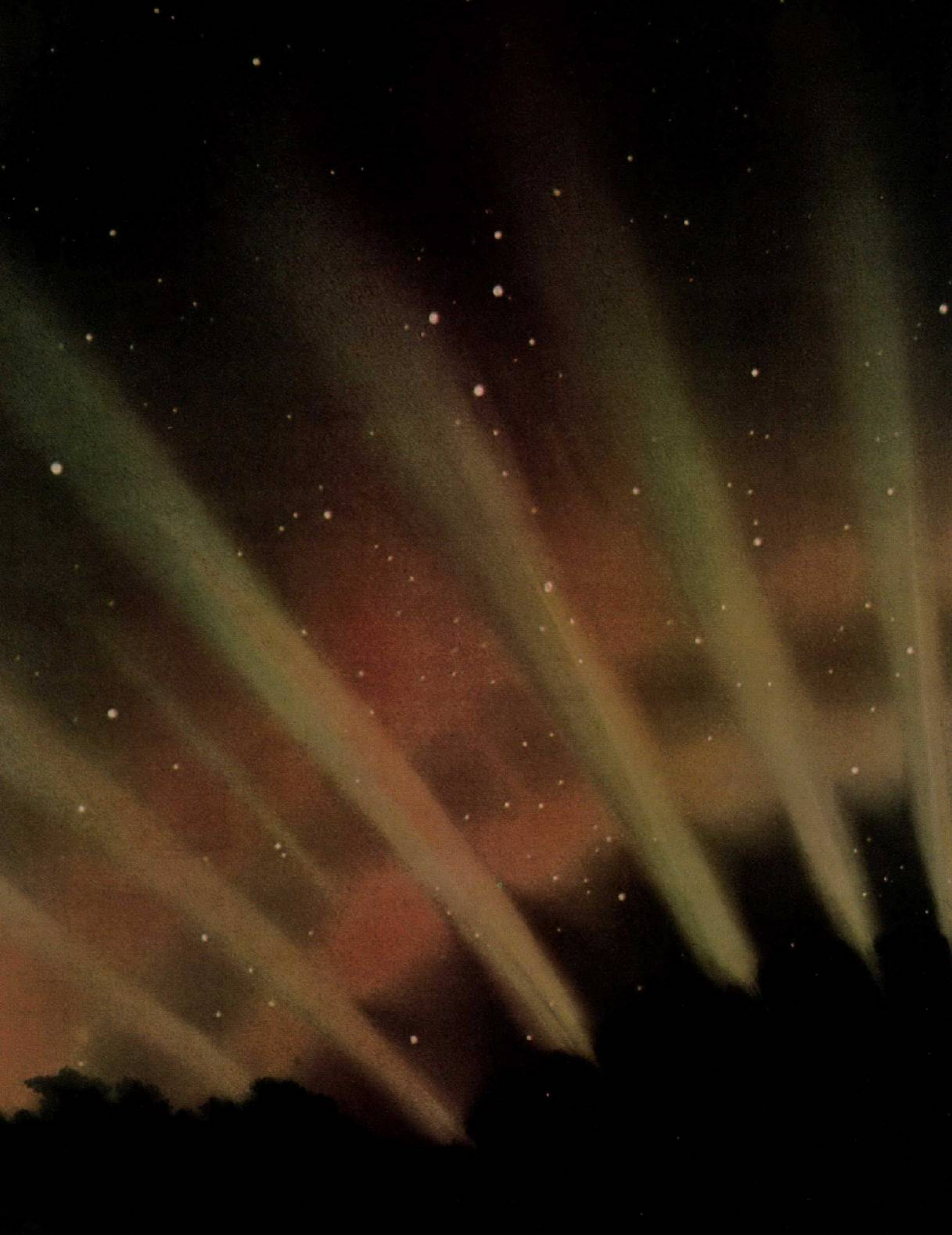
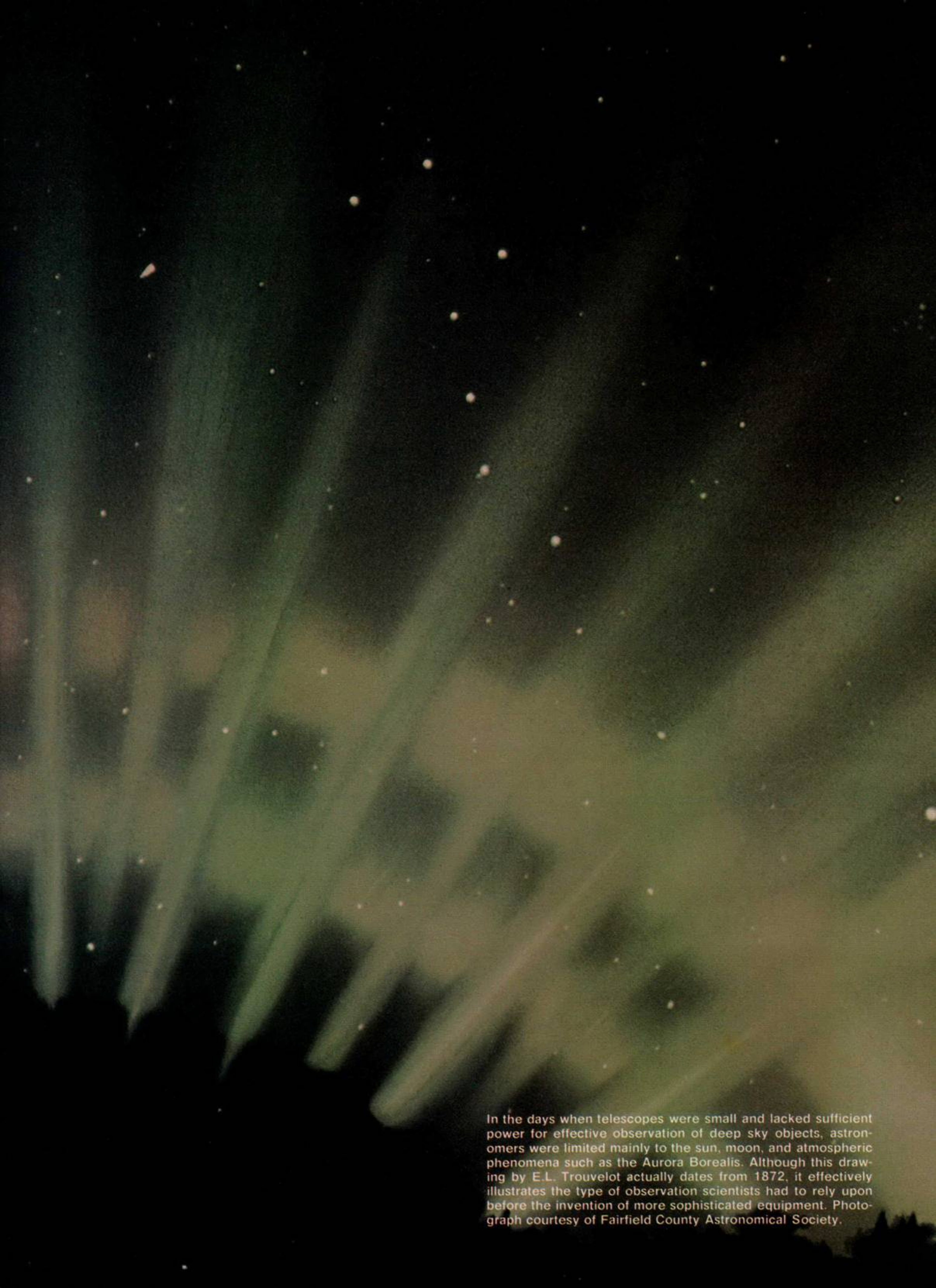
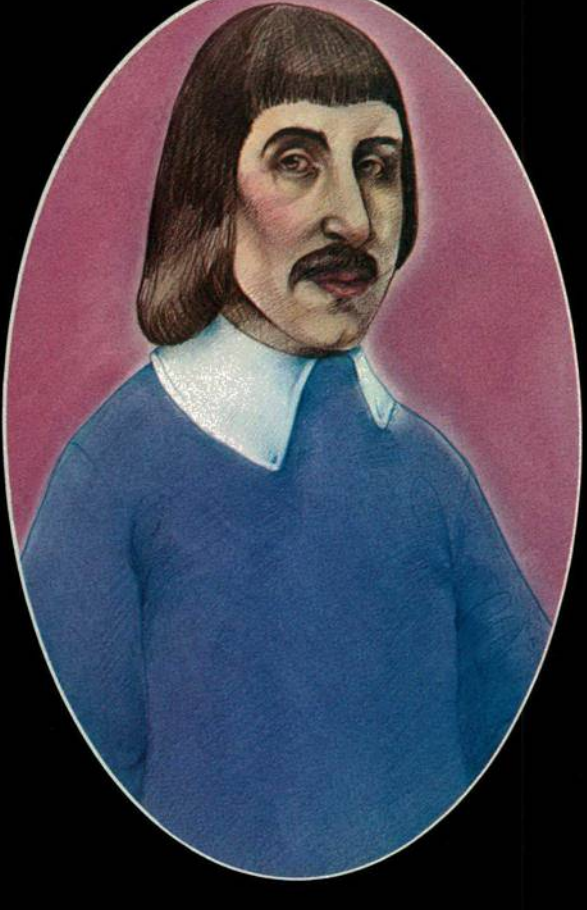


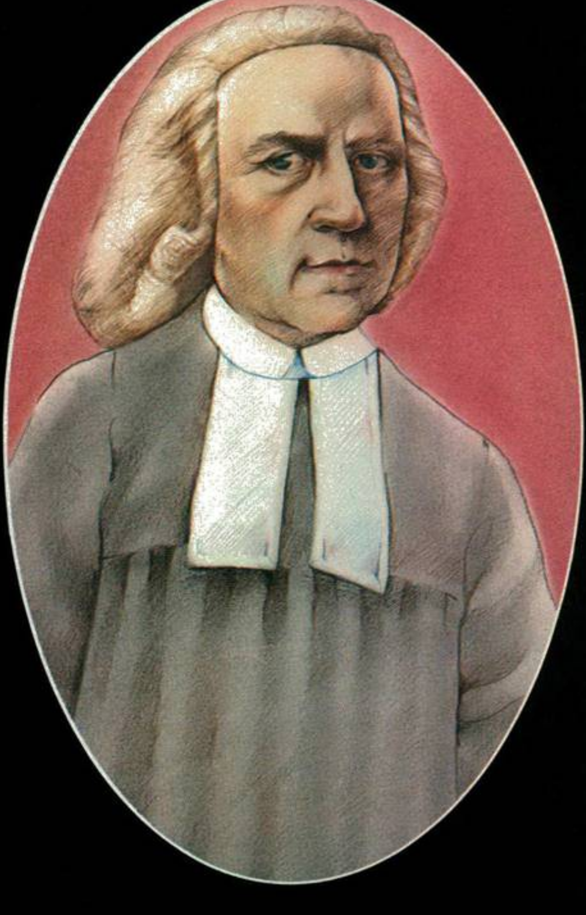






In the days when telescopes were small and lacked sufficient power for effective observation of deep sky objects, astronomers were limited mainly to the sun, moon, and atmospheric phenomena such as the Aurora Borealis. Although this drawing by E.L. Trouvelot actually dates from 1872, it effectively illustrates the type of observation scientists had to rely upon before the invention of more sophisticated equipment. Photograph courtesy of Fairfield County Astronomical Society.





John Winthrop Jr. (1606-1676)

John Winthrop Jr., governor of Connecticut from 1658 until his death, had the foremost reputation in science among New Englanders of the 17th century. Son of the first governor of the Massachusetts Bay Colony, Winthrop was born in England. He emigrated to Boston in 1631, where he became a member of the governor's council four years later — a post he held, off and on, for 14 years.

Winthrop was a practicing physician, an early pioneer in colonial interests in chemistry, and an active amateur astronomer. He was elected a charter member of England's prestigious scientific body, the Royal Society of London, at its first meeting on May 20, 1663. Gov. Winthrop is credited with bringing the first telescope to the New World.

The portraits accompanying the biographical sketches throughout this issue were commissioned by ASTRONOMY and executed by Sharon Nelson.

John Winthrop (1714-1779)

John Winthrop of Massachusetts, America's first notable astronomer, was named Harvard's second Hollis professor of mathematics and natural philosophy in 1739, at the age of 23. An outstanding educator, his students included John Adams and Benjamin Thompson, later Count Rumford.

Winthrop's astronomical work included observations of sunspots, eclipses and transits. He published his work in the *Transactions* of the Royal Society and was named a Fellow in 1766. Chiefly remembered for his 1761 transit of Venus expedition, he later dovoted much of his time to the Revolution. When the necessity to evacuate Cambridge arose, Winthrop had the necessary books and apparatus from Harvard transferred to his home in Concord, where he continued to instruct his students. As a service to his country, he devoted his efforts to solving the most serious problem facing the Continental Army: the lack of gunpowder.

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John Winthrop and was in London negotiating the purchase of a new telescope for Harvard, he was not optimistic about Americans' competence in such matters. He told Maskelyne that he could think of no colony in America "Likely to have a spirit for such an undertaking, unless it be the Massachusetts." While Massachusetts indeed had the astronomical expertise, it also had some deep-rooted political turmoil to contend with. In 1768, the Massachusetts Assembly sent letters to the other colonies suggesting unified opposition to the Townshend Acts. The "taxation without representation" issue raised in the letter caused Great Britain to dissolve the Assembly — in essence withdrawing the source of funding that Winthrop had tapped for his 1761 transit expedition to Newfoundland. Valiant attempts were made to convince Britain's Boston based Gen. Thomas Gage that a unique opportunity existed to promote science, as well as good will between England and her frisky colonists. But no money was forthcoming.

If the colonies started to show signs of political unity during this period, that unity certainly did not extend to science. In Philadelphia, transit enthusiasts sought to demonstrate American astronomical interest and competence as part of a deliberate campaign launched by the new American Philosophical Society. Yet astronomers in Pensylvania and Massachusetts were almost completely isolated from each other. Franklin, pessimistic of his Pennsylvania colleagues, doubted whether a single telescope adequate for making the transit observations existed within the entire province. However, Pennsylvanians rose to the occasion by assembling four telescopes in Philadelphia alone. The American Philosophical Society housed one of the four in a small observatory built especially for the transit. Seven summers later, the Declaration of Independence was first read publicly from the platform of that observatory.

Throughout the colonies, a flurry of activity preceded the transit. In Norriton, Penn., David Rittenhouse used a 144 power refractor and his personally constructed clock and transit telescope, while at Cape Henlopen, Owen Biddle observed with a reflecting telescope. Joseph Brown, Benjamin West and Stephen Hopkins observed from a site in Providence, R.I. that is known today as Transit St. In Newport, the Reverend Ezra Stiles (later to be elected president of Yale) proceeded with his usual enthusiasm. William Alexander in New Jersey, John Page in Virginia, Robert Harpur in New York and John Leeds in Maryland all observed, using various levels of sophistication. In total, 22 independent sets of contact measurements were reported in various journals and newspapers — a fine showing, indeed, for the "provincial" astronomers!

The most interesting question is, of course, "How good were the American observations?" The best results (Rittenhouse's at Norriton), when combined with British results from the Royal Greenwich Observatory, yield a value of the sun's distance nearly equal to the 93 million miles accepted today — but because the observations were difficult, the range of uncertainty was nearly 10 million miles! Significantly, the same was true for English, French and Russian results. We see, therefore, that the issue was not solved in 1769; it would, in fact, become a focal point of American expertise in the following century.

The fact that the American observations were numerous (and some of them clearly equal to the Europeans' best) overshadowed the actual values obtained. The ability to take good data, successfully reduce it into meaningful results, and publish it in a domestic journal demonstrated that the pursuit of astronomy was indeed to be a cornerstone of the emerging American scientific community.

American competence in another area — that of applying the techniques of Newtonian mechanics and astronomy — was demonstrated by Ezra Stiles. Stiles initially served at Yale as a tutor (from 1749 to 1755), and left to enter the ministry at Newport, R.I., where he stayed until Tory parishioners precipitated his expulsion. While at Newport, he calculated an orbit for the comet of 1760, began his extensive series of auroral observations in 1763, and in 1769 observed the transit of Venus in June and a transit of Mercury in November; from the latter he computed the longitude of Newport. In the summer of 1770, he observed and computed the orbit of yet another comet.

Computation of an orbit from several observations of position was one of the great triumphs of Newtonian celestial mechanics. That Stiles and his American contemporaries could use such mathematical procedures on a routine basis attested to their understanding of the astronomical state of the art during the colonial era. The distinction must be made, however, between successfully *using* standard techniques and contributing to *new* developments in the field. The solution of the so-called three-body problem (solving for the positions and motions of three bodies experiencing mutual gravitational attraction) dominated mathematical astronomy during the 18th and well into the 19th centuries. The epoch-making contribution of this most difficult branch of astronomy was that of laying the foundation for the exact mathematical specification of the positions of the sun, stars, planets, moons and comets, for all times past and future. The great advances in this area were exclusively European, with those of the extraordinary French school being particularly important. They were accomplished within the relatively short period of time from Newton's death in 1727 to that of Pierre Simon, Marquis de Laplace, exactly a century later; American isolation from them was almost total.

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Practical Men, Practical Astronomy: 1776-1825

As the 18th century entered its last quarter, astronomy experienced a division into three rather distinct categories: observational, gravitational and descriptive. Observational astronomy refers to that fundamental part of the science concerned with recording the exact positions of heavenly bodies and applying this knowledge to such practical concerns as timekeeping and surveying. Gravitational astronomy is the astronomy of Newton — the application of rigorous mathematical techniques to celestial motions. The actual physical makeup of the different bodies in the universe is the concern of descriptive astronomy. In the rapidly changing scene of America, each division exhibited remarkably rapid progress.

Wartime Astronomy

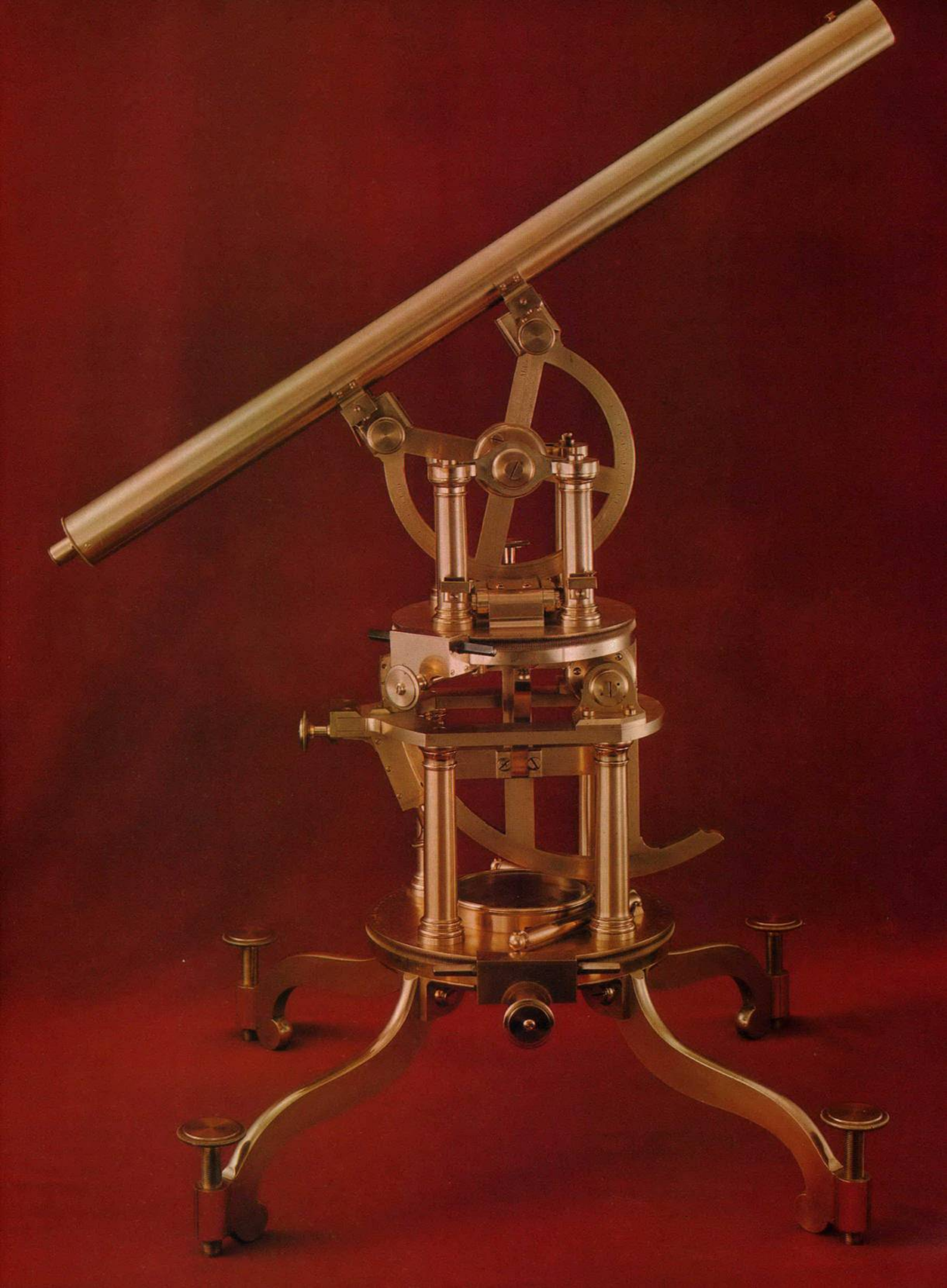
With the outbreak of hostilities on Lexington Green on the morning of April 19, 1775, the development of astronomy in America necessarily proceeded at a much reduced rate — but it did not stop.

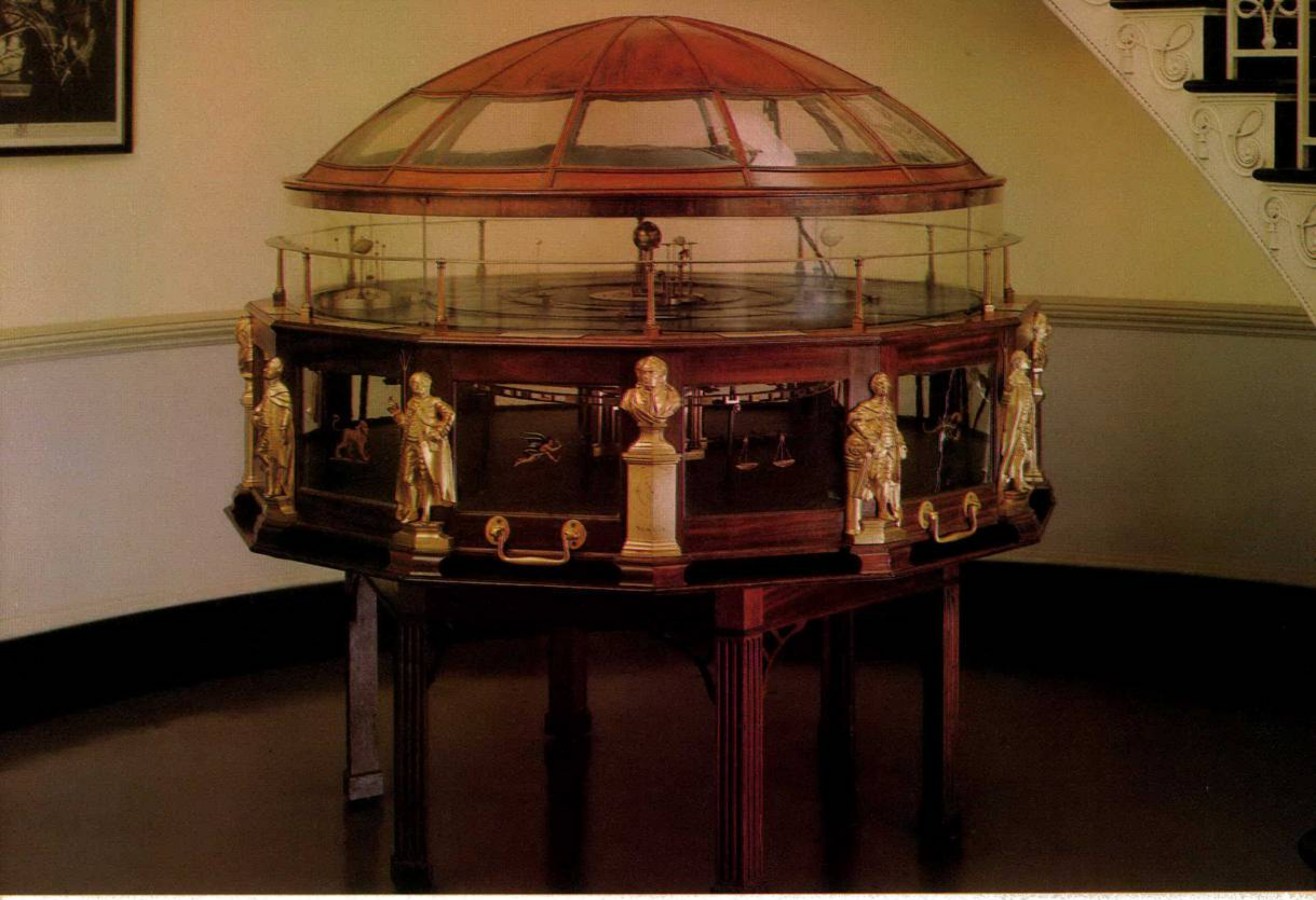
The most renowned academic scientist in the colonies, Prof. John Winthrop of Harvard, continued to teach while enthusiastically working for the Revolution. Despite his heavy involvement in the war, John Adams advanced astronomy in America, devoting considerable effort during the years 1779-80 in forming the American Academy of Arts and Sciences. The academy's purpose was "to cultivate every art and science which may tend to advance the interest, honor, dignity, and happiness of a free, independent and virtuous people." With Harvard, it soon cosponsored an expedition to observe the solar eclipse of Oct. 20, 1780. A truly remarkable feature of this trip was the projected location for the view of totality — Penobscot Bay, Maine — behind British lines! In the Age of Enlightenment, however, science was considered "above the battle"; thus the 10 man American solar eclipse expedition, headed by Samuel Williams, was allowed to proceed. (Williams, a student of Prof. Winthrop, was eventually his successor at Harvard.)

In the first volume of the American Academy's **Memoirs**, published in 1785, Williams described how his observations were carried out even "though involved in all the calamities and distresses of a severe war." He complained how the British officer in charge of the garrison at Penobscot Bay set a time limit "wholly inadequate to our purpose"; nevertheless he described the phenomenon we now call "Baily's Beads" — an effect which occurs the instant before and after totality when bursts of sunlight pass through lunar valleys along the rim of the moon. The effect was "officially" discovered in 1836 (about 56 years later) by British astronomer Francis Baily.

While war's misfortunes continued to ravage the nation, the growth of domestic astronomy proceeded, though often on circuitous paths. In 1778 Ezra Stiles was appointed president of Yale in New Haven, as that city was freed from hostilities with the war's movement southward. Stiles worked with Nemiah Strong, professor of mathematics and natural

Telescope manufacturers of the late 18th and early 19th centuries took great pride in their instruments' appearance as well as their workings. Superb craftsmanship and outstanding metalwork are obvious in this equatorial telescope, made by G. Adams of London. Such an instrument, however, could hardly be used for serious astronomical work; the largest telescope in America did not exceed five inches in aperture until the 1830s. Photograph by Stephen F. Grohe, courtesy of the Harvard Collection of Historical Scientific Instruments.





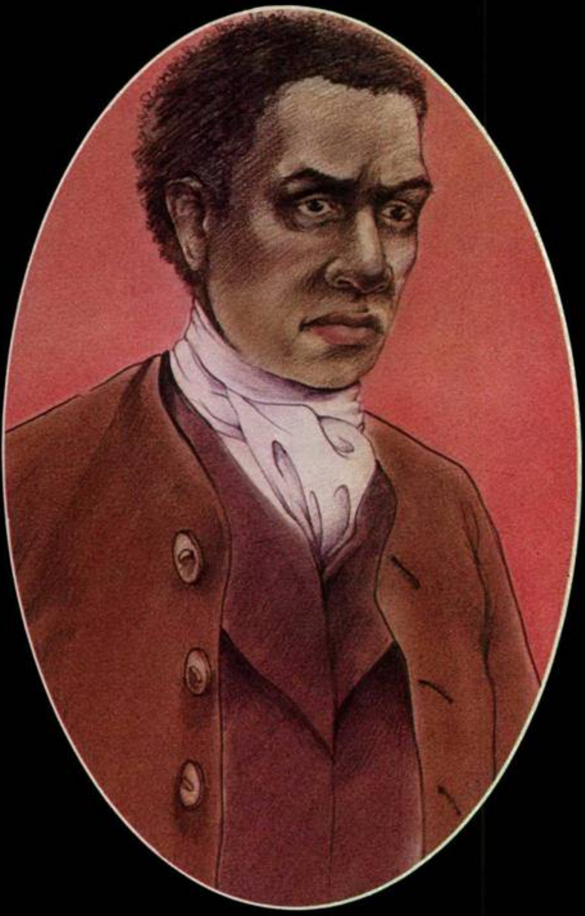
Orreries — mechanical solar systems named after Britain's Earl of Orrery, who first commissioned such a device — were popular devices in the late 18th and early 19th centuries. A great deal of careful work went into their construction, as measurements made from them had to be precise. At left is a detail from an orrery by Benjamin Martin of London; the globes representing Earth and its moon are shown. Note the great care lavished on the tiniest detail. Photograph by Stephen F. Grohe, courtesy of the Harvard Collection of Historical Scientific Instruments. The orrery seen above was built by Joseph Pope, a Massachusetts watchmaker. Among the bronze figures surrounding the base are Benjamin Franklin and Sir Isaac Newton. Photograph by Stephen F. Grohe.

philosophy at Yale, studying the solar eclipse of 1780. Interest in the mechanical universe of the orrery continued, demonstrated by Harvard's acquisition of a second orrery in 1788 — this time of American origin, made by Joseph Pope, a local "mathematician, watch-maker and mechanical genius". The Pope orrery was mounted on a handsome mahogany frame, featuring bronze figures of Franklin, Newton and James Bowdin (donor of the Martin orrery). The rumor that the figures were cast by Paul Revere — like most splendid rumors — persists unconfirmed even to this day. A sidelight connected with the Pope orrery is that Harvard lacked sufficient funds to pay for it, and therefore sought special permission to hold a public lottery to raise the necessary capital.

In later years, Thomas Jefferson initiated a plan to present a Rittenhouse orrery to the king of France as a gift of appreciation for wartime support. Jefferson also had other motives, feeling that in "sending both Rittenhouse and his Orrery to Europe", a blow could be struck against "those flimsy theorists" who might tend to ridicule American expertise in such areas. While Rittenhouse agreed to make one, the plan never materialized, and King Louis XVI's death by guillotine in 1793 effectively closed the issue.

A Permanent American Observatory — Almost A Reality

The earliest attempts to establish a national observatory are closely associated with David Rittenhouse. Following the excitement generated by the 1769 transit of Venus, Rev. John Ewing of Philadelphia suggested that a permanent public observatory be constructed. He enlisted the aid of British Astronomer Royal Nevil Maskelyne and Benjamin Franklin, who was in England at the time. Franklin was pessimistic about American competence in such matters and so nothing developed. In 1775, the American Philosophical Society made a serious effort to establish an observatory to be headed by their then prestigious colleague, David Rittenhouse. In their eloquent petition to the Pennsylvania assembly, the Society argued that among the reasons for constructing a local observatory were "Our Distance from the Chief Observatories in the World" and, alien though it may sound to any 20th century

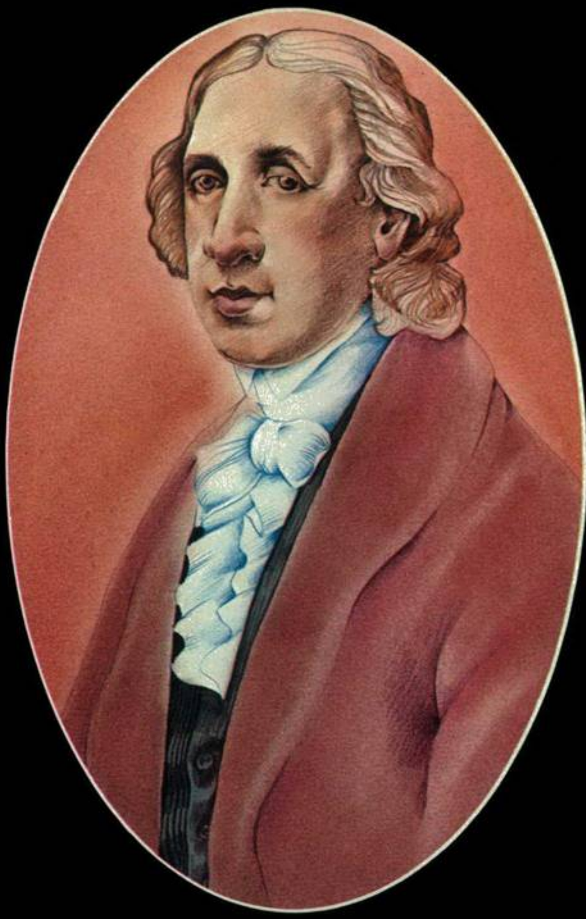


Benjamin Banneker (1731-1806)

Benjamin Banneker became a celebrity in Tidewater, Md. at the age of 22 when he constructed a striking-clock made entirely of wood. That the clock could be built, and indeed worked, was considered quite remarkable by his neighbors — not only because he was an impoverished farmer, but also because he had modeled his clock after a watch he had only borrowed once, and whose workings he had memorized.

At age 58 he was introduced to the discipline of astronomy by some books and instruments lent him by his prestigious neighbor and benefactor, George Ellicott. His mathematical and astronomical abilities developed at an extraordinary rate for a man of his years and position, culminating in his almanacs known collectively as *The Great Adventure*. Thomas Jefferson wrote to him in 1792, "No body wishes more than I do to see such proofs as you exhibit, that nature has given to our black brethren, talents equal to those of the other colors of men, and that the appearance of a want of them is owing to the degraded condition of their existence, both in Africa and America."

As for an astronomical opinion of his almanacs, David Rittenhouse said: ". . . a very extraordinary performance, considering the Colour of the Author. . . . Every Instance of Genius Amongst the Negroes is worthy of attention, because their oppressors seem to lay great stress on their supposed inferior mental abilities."



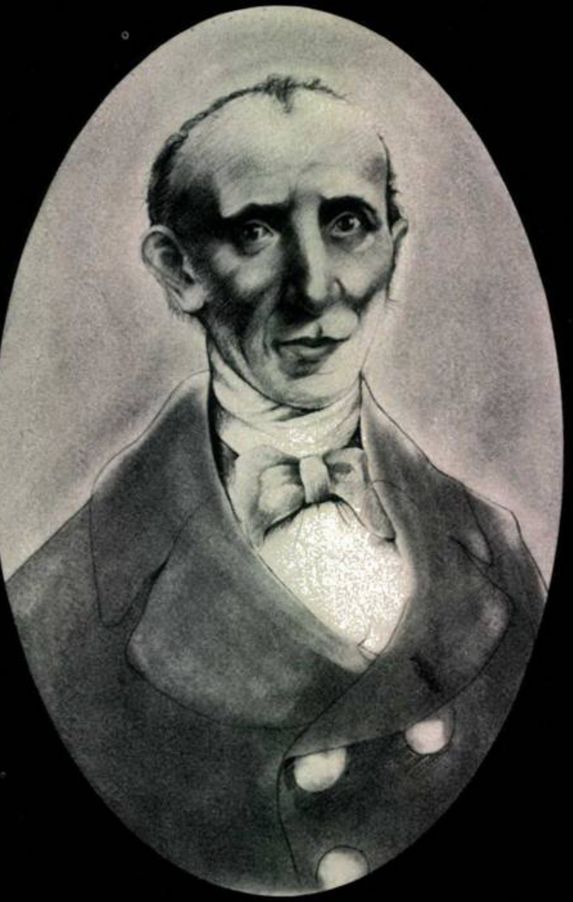
David Rittenhouse (1732-1796)

David Rittenhouse was Pennsylvania's foremost colonial prodigy. He initially earned his living as a clockmaker, and in later years learned and practiced astronomy with the same attention due a precision timepiece. His inner demand for precision led him to use strands of a spider web to form one of the first reticule (crosshair) eyepieces.

Rittenhouse's superior knowledge of astronomy and mathematics was self-taught. Among his findings was his discovery of Venus' atmosphere made during his observation of the 1769 transit, and independent of a Russian observation made during a transit eight years earlier.

Throughout the war years, Rittenhouse devoted much of his energy to the Revolutionary cause. He served as engineer for the Pennsylvania Committee of Safety, filled Benjamin Franklin's seat in the state assembly, and served as state treasurer until the end of the war. He surveyed for fortifications, supervised munitions manufacture, and demonstrated the "relevance" of basic research by experimenting on the use of telescopic sights for rifles carried by the Continental Army.

Upon Franklin's death in 1791, Rittenhouse became president of the American Philosophical Society. In 1795, he was named an honorary member of the Royal Society of London — an apt example of the ease with which members of the scientific community could cross hostile international boundaries.



Nathaniel Bowditch (1773-1838)

Nathaniel Bowditch was born in Salem, Mass., in the year of the Boston Tea Party. His education was given an invaluable boost by an act of war — in 1780, a Yankee pirate captured an English vessel on her way from Galway, Ireland, to London. The booty included the "philosophical library" of the famed Irish scholar Dr. Richard Kirwan. Several of Salem's leading citizens purchased the books, giving Salem the finest scientific library north of Philadelphia.

Early in Bowditch's astronomical career, he described the great solar eclipse of 1806 (nearly five minutes of totality) and collected reports of the spectacular meteor which exploded over Weston, Conn. in 1807. In 1806 he was offered the Hollis professorship of mathematics and natural philosophy at Harvard, but he declined on the grounds that he wouldn't fit in with the academic types there. In 1818, Thomas Jefferson offered Bowditch a post at the University of Virginia, and in 1820, Secretary of War John C. Calhoun offered a position at West Point. Bowditch declined both offers, presumably on the same grounds as the Harvard position, or perhaps because they meant leaving his beloved New England. (In 1814, he had associated with local Federalist radicals who wanted New England to secede from the Union.)

As for Bowditch's reputation abroad, he was elected to the Royal Astronomical Society in 1829 — the first American to be so honored. It was not a complete triumph, however, for the society listed his address as "Boston in Connecticut".

visitor to Philadelphia, "the Purity and Serenity of our Atmosphere". The plan might have succeeded if the shooting on Lexington Green had not occurred, for Maskelyne, a member of the society, was then forced to withdraw from the project because of "the present unhappy situation of American affairs."

As the war ended, Rittenhouse started to construct his own brick observatory. British astronomer William Herschel had made the spectacular discovery of a new planet in 1781; thus when Rittenhouse's structure was completed in 1783, Uranus was one of the first objects he regularly observed. Local supporters tried to obtain public funds to convert his private observatory into a public one, even going as far as to suggest a mini-astronomer royal ("Astronomer to the State of Pennsylvania") — a post obviously tailor-made for Rittenhouse. The assembly liked the idea but not the financial commitment needed to make it a reality.

Postwar possibilities of an American observatory even excited Benjamin Franklin, who had long been pessimistic about American endeavors in astronomy. The ever-increasing number of exciting astronomical discoveries made on this continent prompted Franklin to declare, "I begin to be almost sorry I was born so soon." Only Franklin had the reputation (and indeed the nerve) to write to Herschel, suggesting that "Had Fortune plac'd you in this part of America, your Progress in these Discoveries might have been more rapid." In typical Franklin fashion, he went on to quantitatively justify his bold suggestion by showing that the clean American air would permit 1/3 more days for observation than available in England!

Franklin knew well of what he spoke, for descriptive astronomy was the new astronomy of the day and Herschel, indeed, was its prophet. The spectacular contributions made by Herschel to the development of astronomy were enough to intimidate any European astronomer — not to mention astronomers in the developing country that was America at the end of the 18th century.

Herschel began his astronomical career in 1774 when, at age 36, he built his first telescope; only seven years later he discovered Uranus during one of his sky surveys with a seven foot long Newtonian reflector. In 1783, he completed a reflecting telescope 20 feet in length with a mirror 18 inches in diameter. Ultimately, he built a giant 40 foot instrument with a four foot mirror — large even by 20th century standards! These powerful instruments opened up the heavens in a way unimaginable to American astron-

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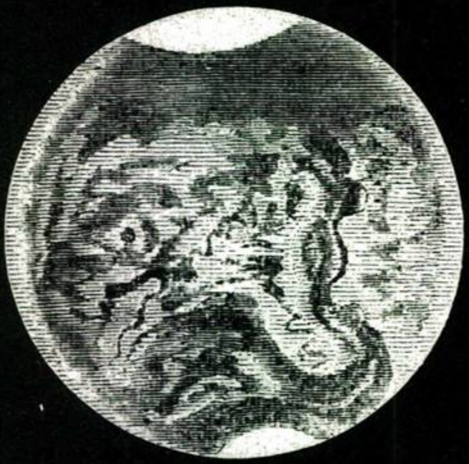

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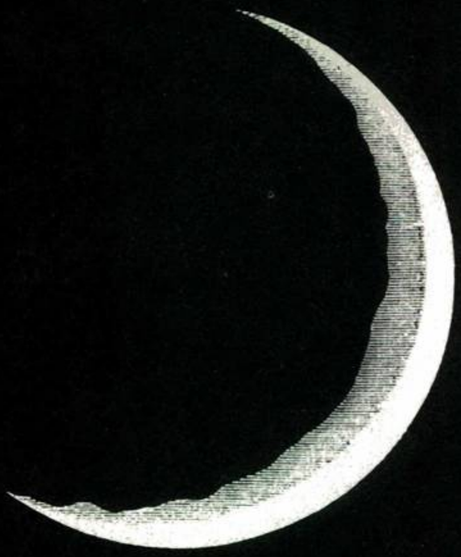

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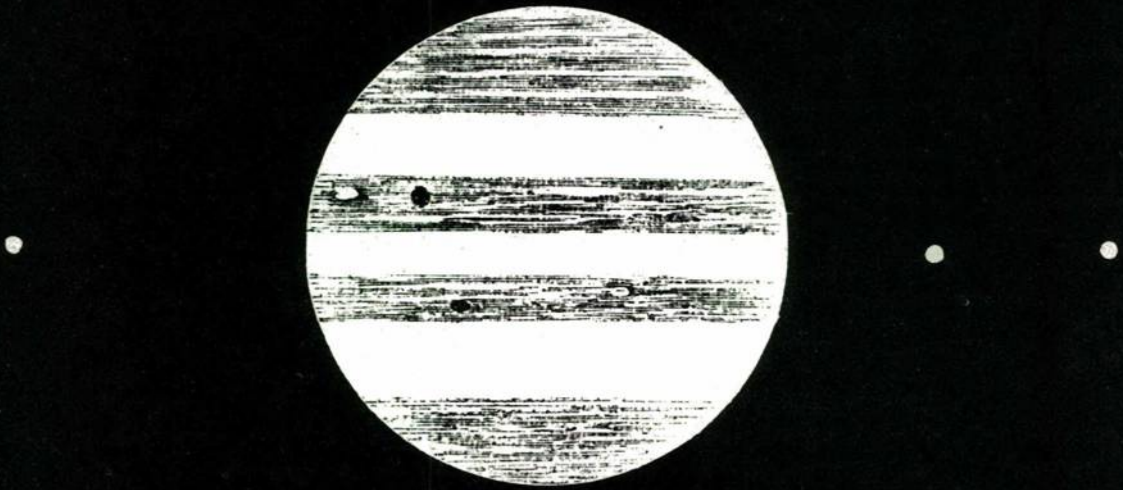

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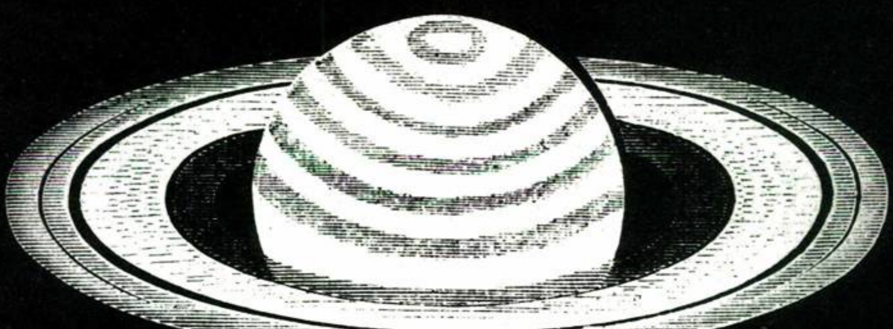

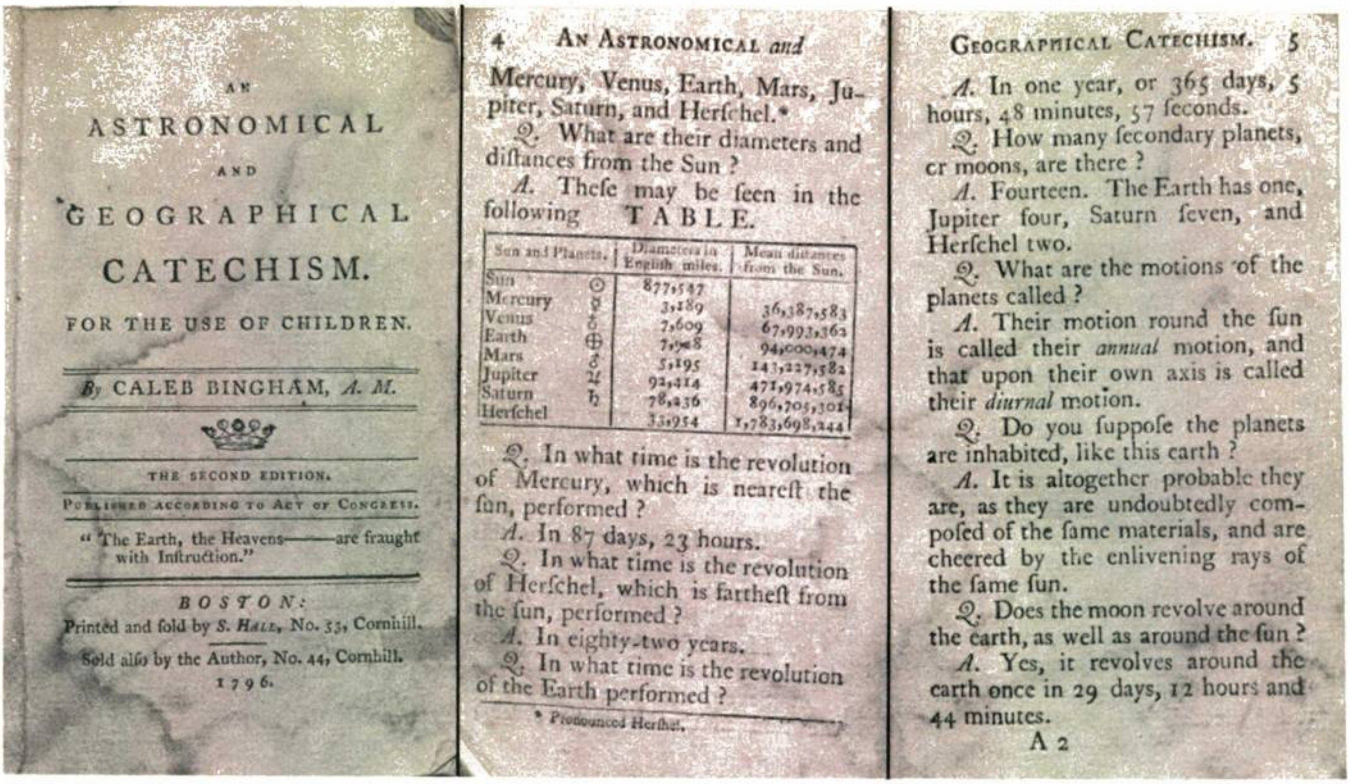

AN

ASTRONOMICAL

AND

GEOGRAPHICAL

CATECHISM.

FOR THE USE OF CHILDREN.

By CALEB BINGHAM, *A. M.*

THE SECOND EDITION.

PUBLISHED ACCORDING TO ACT OF CONGREſS.

"The Earth, the Heavens——are fraught with Inſtruction."

BOSTON:
Printed and ſold by *S. HALL*, No. 53, Cornhill.
Sold alſo by the Author, No. 44, Cornhill.
1796.

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4 AN ASTRONOMICAL *and*

Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Herſchel.*

Q. What are their diameters and diſtances from the Sun?

A. Theſe may be ſeen in the following TABLE.

Sun and Planets.		Diameters in English miles.	Mean diſtances from the Sun.
Sun	☉	877,547	
Mercury	☿	3,189	36,387,583
Venus	♀	7,609	67,993,362
Earth	⊕	7,968	94,000,474
Mars	♂	5,195	143,227,582
Jupiter	♃	92,414	471,974,585
Saturn	♄	78,236	896,705,301
Herſchel		33,954	1,783,698,244

Q. In what time is the revolution of Mercury, which is neareſt the ſun, performed?

A. In 87 days, 23 hours.

Q. In what time is the revolution of Herſchel, which is fartheſt from the ſun, performed?

A. In eighty-two years.

Q. In what time is the revolution of the Earth performed?

* Pronounced Herſhel.

GEOGRAPHICAL CATECHISM. 5

A. In one year, or 365 days, 5 hours, 48 minutes, 57 ſeconds.

Q. How many ſecondary planets, or moons, are there?

A. Fourteen. The Earth has one, Jupiter four, Saturn ſeven, and Herſchel two.

Q. What are the motions of the planets called?

A. Their motion round the ſun is called their *annual* motion, and that upon their own axis is called their *diurnal* motion.

Q. Do you ſuppoſe the planets are inhabited, like this earth?

A. It is altogether probable they are, as they are undoubtedly compoſed of the ſame materials, and are cheered by the enlivening rays of the ſame ſun.

Q. Does the moon revolve around the earth, as well as around the ſun?

A. Yes, it revolves around the earth once in 29 days, 12 hours and 44 minutes.

A 2

Before the advent of photography, scientists had to communicate their findings and observations through drawings. On the opposite page is the frontispiece of *A Treatise on Astronomy* by Elias Loomis of Yale; pictured are Mars, the moon, Jupiter and Saturn. Photograph by Benjamin Morse. Above are three pages from a children's Astronomical Catechism. Note the use of the name "Herschel" for the planet Uranus. Photographs courtesy of the American Antiquarian Society.

omers, for at the time of Herschel's death in 1822, America did not yet possess a telescope with an aperture of five inches!

Although these were incredibly productive years for descriptive astronomy (1774-1822), America remained the passive pupil as news of discoveries flowed westward across the Atlantic. Two new satellites, each, for the giant planets Saturn and Uranus, the oblateness of Saturn, bands on Jupiter, the seasonally varying Martian polar caps, and the asteroids (or minor planets) were all added to man's knowledge of the solar system. European astronomers measured the large-scale distribution of stars in space by systematic star counts, leading to the disk shaped or grindstone model of the universe. Star clusters, nebulae and the possible "island universe" were compiled in catalogs. Binary star systems were discovered and the sun's motion through space was measured. Some stars were even found to vary in brightness. That was the new descriptive astronomy at its best, and America was simply unable to compete with such a rapidly developing field. In that climate, however, America's turn to the practical side of astronomy was perhaps inevitable.

American Astronomy Becomes Practical

During the early years of the American republic, the three main concerns of the struggling nation were agriculture, manufacturing and commerce. These vital necessities caused "basic research" or "textbook knowledge" to be frowned upon. Astronomy, so popular in the early colonial days, became particularly suspect. Indeed, college graduates of 1790 were told in one magazine, "You are not to live in the sun, nor the moon, nor ride upon the tails of a comet.... A *few* astronomers are enough for an age!" The "Promotion of Useful Knowledge" became the chief concern of the Philosophical Society and the American Academy of Arts and Sciences.

Three areas where astronomical techniques could be applied to the needs of the nation were surveying, almanac writing and navigation. David Rittenhouse, in Benjamin Franklin's image, always had a reputation for being a "practical" man. After the war, he continued to survey by special Congressional appointments, helping settle territorial disputes. He clearly didn't enjoy it though, and in a letter to Andrew Ellicott, geographer of the United States, said that after the New York-Massachusetts boundary was settled in 1789, he would "bid adieu, forever, to all running of lines."

In applying astronomical knowledge to useful causes, however, no Americans succeeded more than Benjamin Banneker and Nathaniel Bowditch.

Born in 1731, Banneker was the son of a freed slave. While he left no lasting mark on the science of astronomy, his mastery of difficult astronomical techniques catapulted astronomy into the public and political domain. Banneker's first astronomical work, an unpublished almanac for 1791 circulated by the Maryland Abolitionist movement, led to the 60 year old black being named to the surveying team assigned the task of determining the borders of the nation's new Capitol on the Potomac. That survey and the seven almanacs he later published demonstrated his proficiency in two of the areas where astronomy was considered adaptable to the nation's goals. "Better than any other lesson to be derived from Banneker's life and work", writes his biographer Silvio Bedini, "is the one he so admirably exemplified: that the thirst for knowledge is not limited to youth, and that the process of learning recognizes no barriers of race or creed."

The application of astronomical principles to the needs of early 19th century America reached its pinnacle in Nathaniel Bowditch, a self-educated man. His work was important to the development of astronomy because it introduced the use of new, sophisticated mathematical techniques developed by French astronomers to their American and English counterparts.

Bowditch's family had been shipmasters for over 100 years, so in 1795 he went to sea to merge celestial navigation principles with practical experience. The fundamental celestial reference books of that period were the English editions of Moore's **Practical Navigator** and Nevil Maskelyne's **Requisite Tables** for the **Nautical Almanac**; Banneker and other American almanac makers had long relied on them. Bowditch meticulously poured through these books, and found discrepancies in Moore's volume. This lead to Moore's revised edition, **The New Practical Navigator** which referred to revisions by a "skillful mathematician and navigator". Bowditch pressed on with further changes, but the task became hopeless; he uncovered 8,000 errors in Moore's work (2,000 of which he traced to errors in Maskelyne's **Requisite Tables**).

Bowditch finally produced a new book — patriotically entitled **The New American Practical Navigator**. Published both in the United States and England in 1802, this book was a monumental effort, exceeding 600 pages in length, and filled with detailed explanations, tables, maps and magnificent illustrations produced from copper plates. Technically, it was a masterpiece, and so useful it was a veritable Bible to seamen. To sail with Bowditch — whether the man or his book — assured success. One ship's captain was so taken by Bowditch's ability to explain celestial navigation that he boasted, "I have a crew of 12 men, every one of whom can take and work a lunar observation as well, for all practical purposes, as Sir Isaac Newton himself, were he alive."

The early decades of the 19th century were marked by amazing growth in descriptive astronomy. Spurred by the rise of large telescopes, Herschel and other European astronomers set a rapid pace of discovery.

In gravitational astronomy, giants of the German scientific school included Carl Friedrich Gauss (1777-1855), Friedrich Wilhelm Bessel (1784-1846) and Johann Franz Encke (1791-1865). They greatly advanced our ability to mathematically handle experimental data, to derive celestial orbits, and to account for gravitational perturbations upon the two body problem caused by "extraneous masses". In 1838, Bessel determined the parallax of a star (its shift in angular position due to the annual motion of Earth about the sun) which was a long overdue observational verification of Copernicus, using the star 61 Cygni, approximately 10 light-years distant. The angular shift in position was therefore about 1/3 second of arc — a remarkably delicate measurement then impossible on our side of the Atlantic.

With mathematical astronomy still beyond access to the American astronomers, Bowditch was a major figure in its introduction to the English speaking world. In the decades following the outbreak of the War of 1812, Bowditch carried out the enormous task of translating — with commentary — Pierre Simon, Marquis de Laplace's epic summary of mathematical astronomy, **Mécanique Céleste.** The translations were published in four volumes from 1824 to 1839; Laplace's fifth volume was only partially completed when Bowditch died.

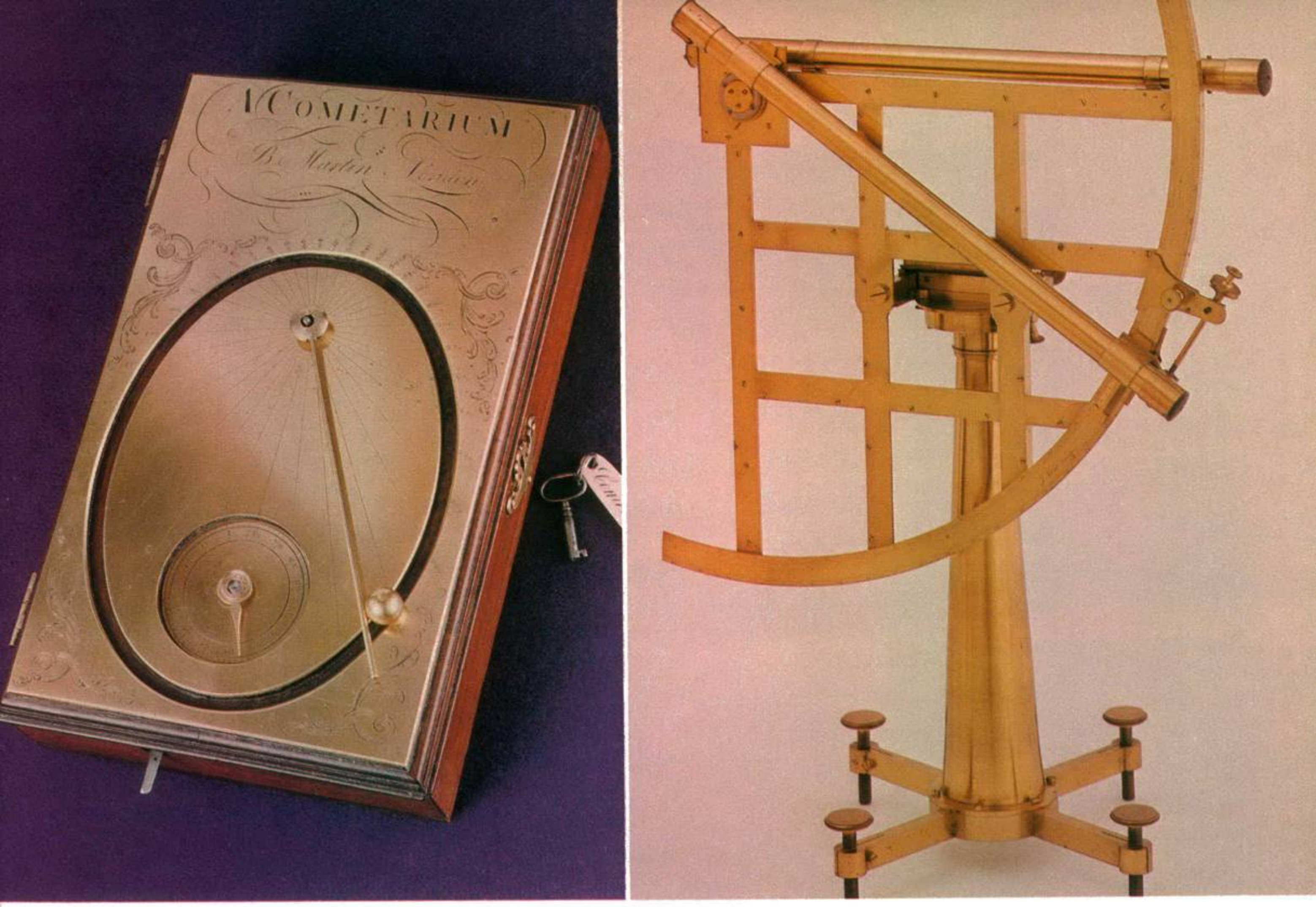
Bowditch's translations assumed an importance far beyond American acclaim, for the mathematical methods of astronomy developed in Europe were nearly as unknown to the British astronomers as they were to the Americans. Just as British shipmasters had become dependent upon **The New American Practical Navigator**, so did Bowditch's translation of Laplace become the only really good volume available to English astronomers.

Assessment of Early American Contributions

We have seen how the role of astronomy in early America was commensurate with the country's status as a developing nation. The elegance and mathematical rigor of European astronomy was yet to be embraced and the lack of adequate telescopes kept American observers at an amateur level. Astronomy's domestic survival, in fact, seemed to be due almost entirely to the raw enthusiasm of John Adams' "free, independent and virtuous people". The high point of the early era is probably a choice between the far reaching consequences of the 1769 transit of Venus activities and the solitary scholarship of Nathaniel Bowditch. The transit's effect was of more importance to Americans, while the contributions of Bowditch were more fundamental to the course of astronomy.

Perhaps the best testament to the lasting work of Bowditch was given by the latter day American astronomer, Simon Newcomb, in his **Sidelights on Astronomy**:

"While the great mathematical astronomers of Europe were laying the foundation of celestial mechanics their writings were a sealed book to everyone on this side of the Atlantic, and so remained until Bowditch appeared, early in the present century. His translation of **Mécanique Céleste** made



Left: A cometarium was an instrument somewhat similar to an orrery, in that it was used to predict and describe the orbits of comets around the sun to any degree of eccentricity. This particular model was constructed by Benjamin Martin of London. Right: This instrument is the Bird quadrant. Like its near relation, the sextant, a quadrant was used to measure altitudes. The beauty of this model lies in the exquisite precision of its construction. Photographs by Stephen F. Grohe, courtesy of the Harvard Collection of Historical Scientific Instruments.

an epoch in American science by bringing the great work of Laplace down to the reach of the best American students of his time."

Concerning early American astronomy, Newcomb further commented:

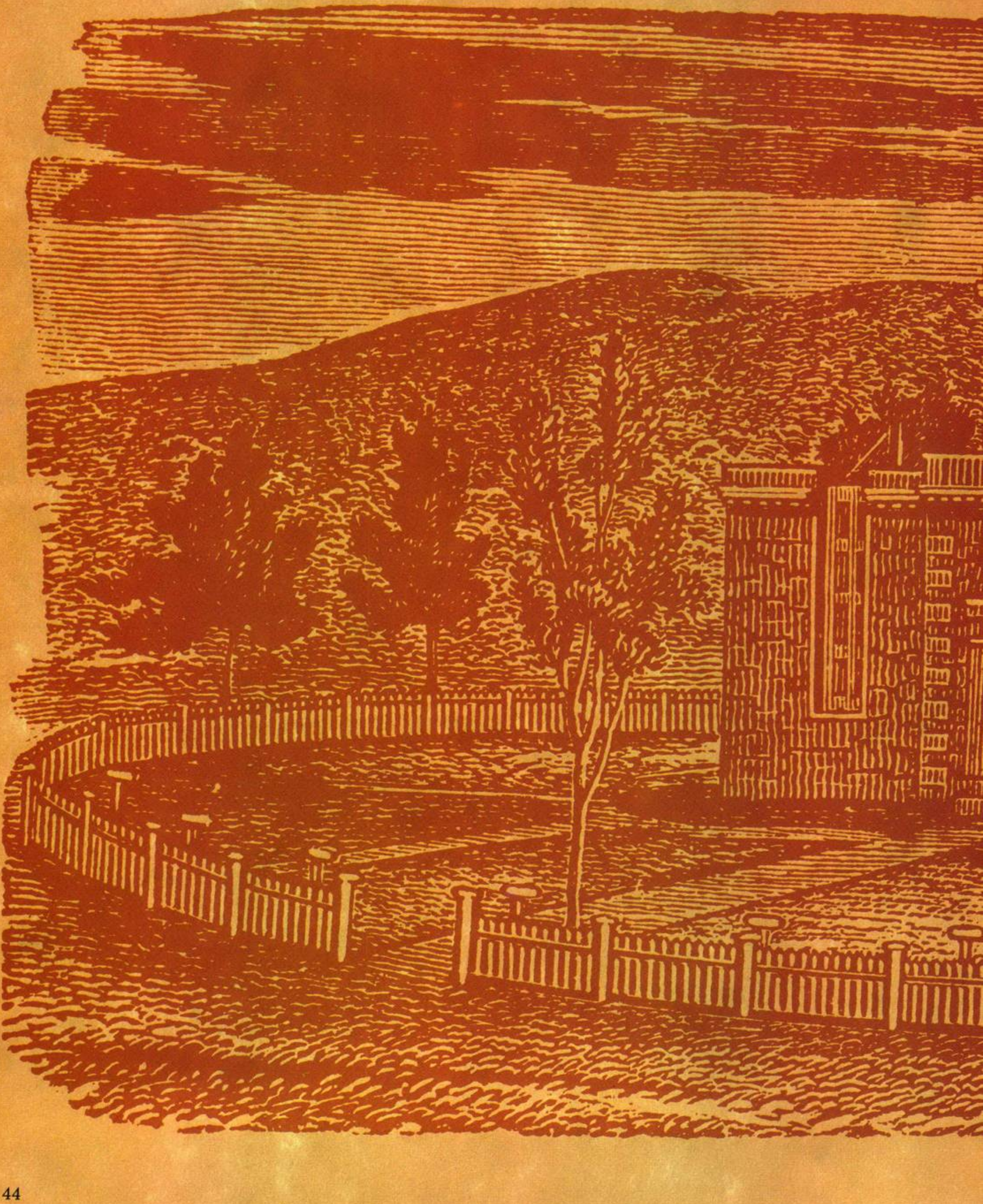
"American astronomers must always honor the names of Rittenhouse and Bowditch. And yet in one respect their work was disappointing in results. Neither of them was the founder of a school. Rittenhouse left no successor to carry on his work. The help which Bowditch afforded his generation was invaluable to isolated students who, here and there, dived alone and unaided into the mysteries of celestial motions. His work was not mainly in observational astronomy, and therefore did not materially influence that branch of science."

Newcomb's meaning is clear. American astronomers were not at the forefront of the science during the colonial period, or during the early republic. Basic instruction and simple observations were their domain, always with a look toward application rather than theoretical speculation. American astronomers were, however, well aware of their striving status, and perhaps a bit too sensitive about it. They wanted to be accepted as equals by Europeans and tried mightily to demonstrate their competence.

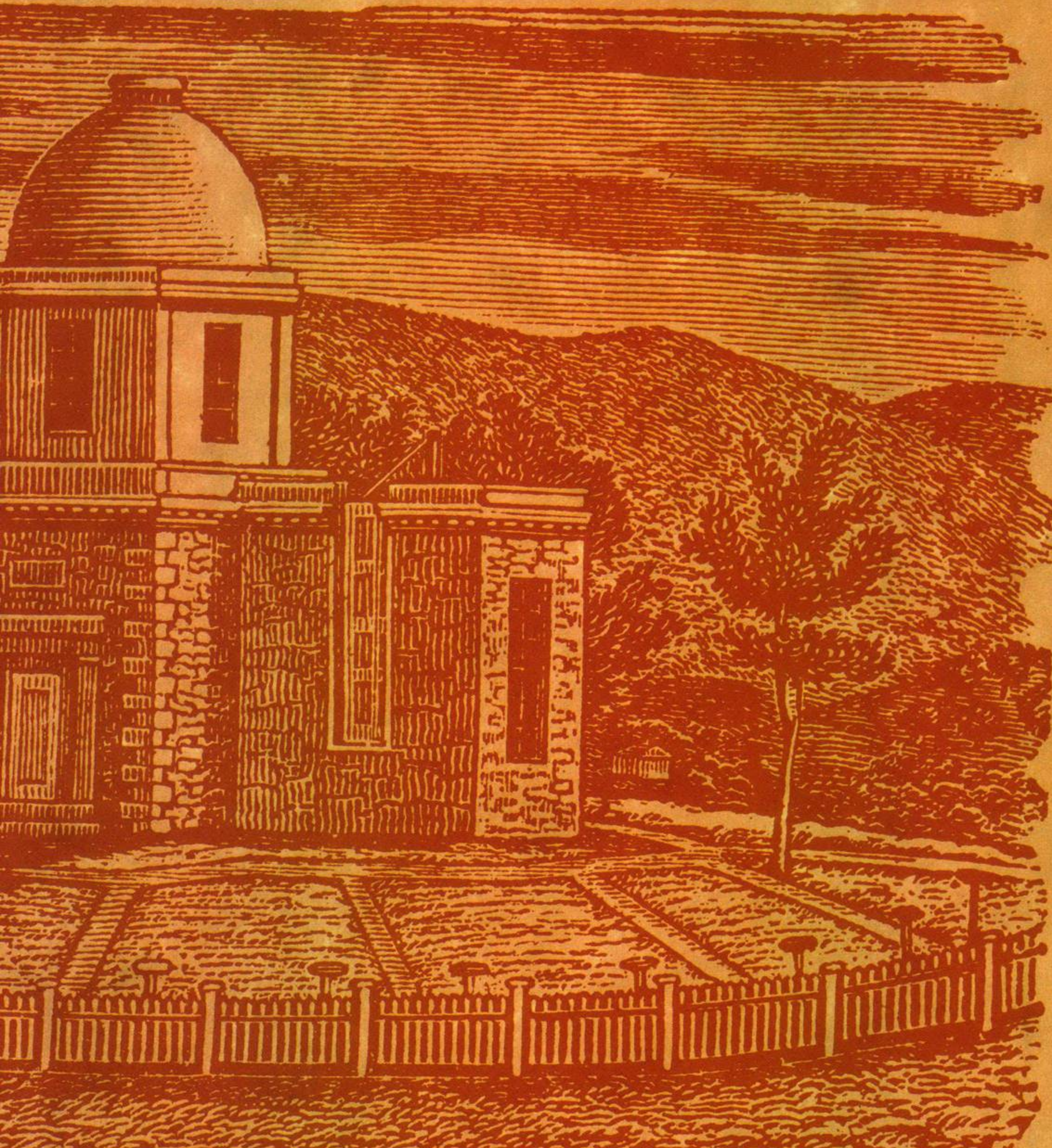
Humility seemed the best approach to the American Academy, so in the preface to its first volume of **Memoirs** (1785) it noted that, "The astronomical and mathematical papers in this volume will, perhaps, be the least entertaining of any of the collection, and will have the smallest number of readers.... Few, if any of them, contain deep speculations and obtruse researches and calculations: but they are chiefly of the practical kind."

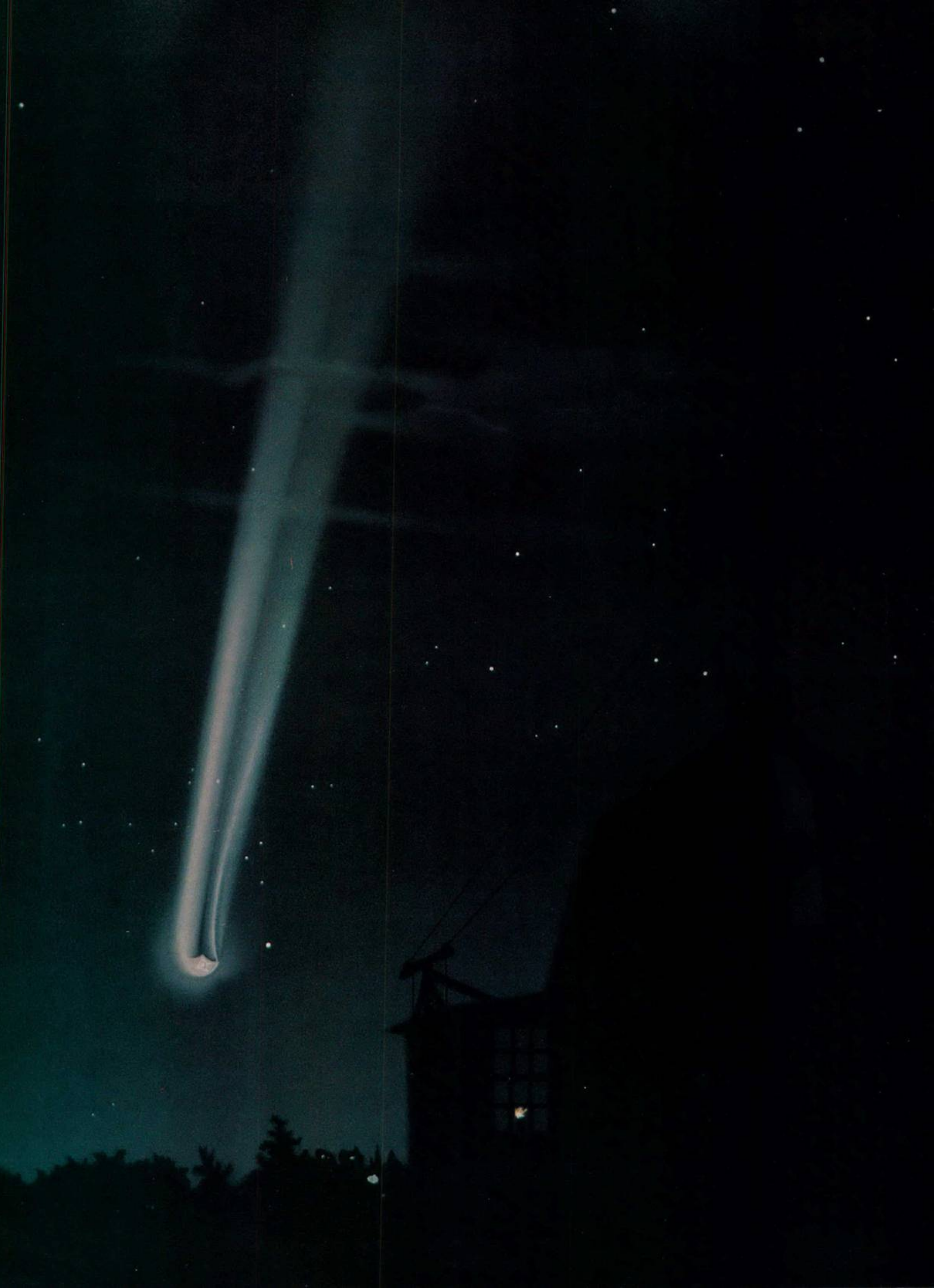
It must have been with particular pleasure, therefore, that when the volume was reviewed in 1788 by the British magazine **Monthly Review**, it was declared to be "proof that philosophical pursuits are carried on with vigor in the American States." European approval of America's early endeavors was not always the case, however, for in the previous year, the second volume of **Transactions** of the American Philosophical Society (1786) was condemned by the British **Critical Review** as being full of "empty speculation and disputed theories". It further suggested that Americans "might be more usefully employed in accumulating facts than in constructing systems."

ASTRONOMY



COMES OF AGE: 1825-1840





The lack of a national observatory was a pain suffered by American astronomers well into the 19th century. The search for the first American observatory is as "dangerous" an undertaking as to try to select America's "finest city" or "most tasty" apple pie. Lost records, distortions, vehement emotions and clever fantasies confuse the search. Since no claim for the first American observatory refers to a structure built after 1840, we will refer mainly to the wave of observatory building which swept America during the decade prior to 1840. Lingering memories of the 1769 transit of Venus, the spectacular Leonids display of 1833, and growing anticipation for the upcoming return of Halley's comet in 1835 all may have contributed to the growing enthusiasm for astronomy in America.

If one disregards structures which might be classified as 1) temporary observatories, such as the surveying stations set up by Mason and Dixon in 1763; 2) makeshift observatories (for example, the Yale Observatory of 1830 consisted of a new telescope installed in their Athenaeum tower), and 3) mere repositories of astronomical apparatus, such as Prof. Winthrop's house in Concord, Mass., then David Rittenhouse's little octagonal brick observatory built on the corner of Seventh and Arch Streets in Philadelphia in 1783 may well be called the first regular astronomical observatory. It was built expressly for that purpose and manned by an expert observer in America.

The great French astronomer Lalande wrote in the preface to his famous **Astronomie** that the only observatory in America known to him in 1792 was that of Rittenhouse. (In his 1771 edition, Lalande had mentioned only European observatories.) After Rittenhouse died in 1796, his observatory was no longer used.

In searching for the oldest astronomical observatory building still standing in America, Prof. Willis Milham of Williams College's Hopkins Observatory has presented ample evidence to show that the title goes to the Hopkins Observatory in Williamstown, Mass. Named after Albert F. Hopkins (1807-1872), professor of natural philosophy and astronomy under whose direction it was constructed (1837), it was dedicated on June 12, 1838.

Several early American observatories were associated with educational institutions. At the College of William and Mary, an early observatory was apparently destroyed during the last years of the Revolutionary War. There, colonial astronomy was most associated with Bishop James Madison (1749-1812), who graduated from the college in 1771. Appointed professor of natural philosophy and mathematics two years later, he was made president in 1777 and continued in office until his death.

In 1830, Yale possessed the largest telescope in America — five inches in diameter, with a ten foot focal length. Placed in the college's Athenaeum tower, it was mounted on casters so it could be pushed easily from window to window. Using that telescope, Denison Olmsted and Elias Loomis were the first Americans to spot Halley's comet during its approach to the sun.

During the Olmsted and Loomis years, astronomy flourished at Yale. While Olmsted's research included meteors and aurorae, he is most remembered for his college textbooks on astronomy and natural philosophy. Loomis also added to the textbook tradition at Yale and produced — in 1850 — a noteworthy history of American astronomy. In later years, he unified all the auroral observations made by New Englanders. The Loomis name is also associated with the observatory at Western Reserve College in Hudson, Ohio; he was a professor of mathematics and natural philosophy at Western Reserve from 1836 to 1844.

At the University of North Carolina, construction began in 1830 on an observatory — only 35 years after the university was founded. Built under the direction of President Joseph Caldwell, who funded most of the project with his own money, the observatory cost $430.29-1/2 and was situated on a hill near the Chapel Hill graveyard. After Caldwell's death in 1835, the building fell into decay. In 1838, according to the story, it was set aflame by some students, and Caldwell's successor appropriated the surviving bricks to build a kitchen.

At Wesleyan University in Middletown, Conn., a small wooden observatory was built in 1838-39 to house a six inch refractor — the largest in the U.S. at that time. The observatory was moved in 1854; then in 1868, it suffered the ignominious fate of being transformed into a chicken coop. Observational astronomy at Wesleyan fortunately survived such irreverance. A second observatory was started the same year to house an Alvan Clark 12 inch refractor, and much later — in 1914 — construction of the Van Vleck Observatory commenced.

The origin of the Harvard College Observatory is tied to the name of William Cranch Bond. In 1815, the Harvard Corporation formed a committee to consider the subject of an "official" observatory. Both Bond and Nathaniel Bowditch served on the committee, but nothing materialized. In 1822, a similar episode occurred. Finally, in October 1839,

Caption for pages 44 & 45

This 19th century woodcut shows the oldest standing American astronomical observatory — Hopkins Observatory in Williamstown, Mass. Dedicated in 1838, it was established six years before the first national observatory, the United States Naval Observatory, was built. Williams College — Hopkins Observatory photograph.

This drawing by E.L. Trouvelot is of the Great Comet of 1881. The observatory in the foreground could well be one of the many that were begun in the 1830s, when a great wave of observatory building swept the nation. Photograph courtesy of Fairfield County Astronomical Society.

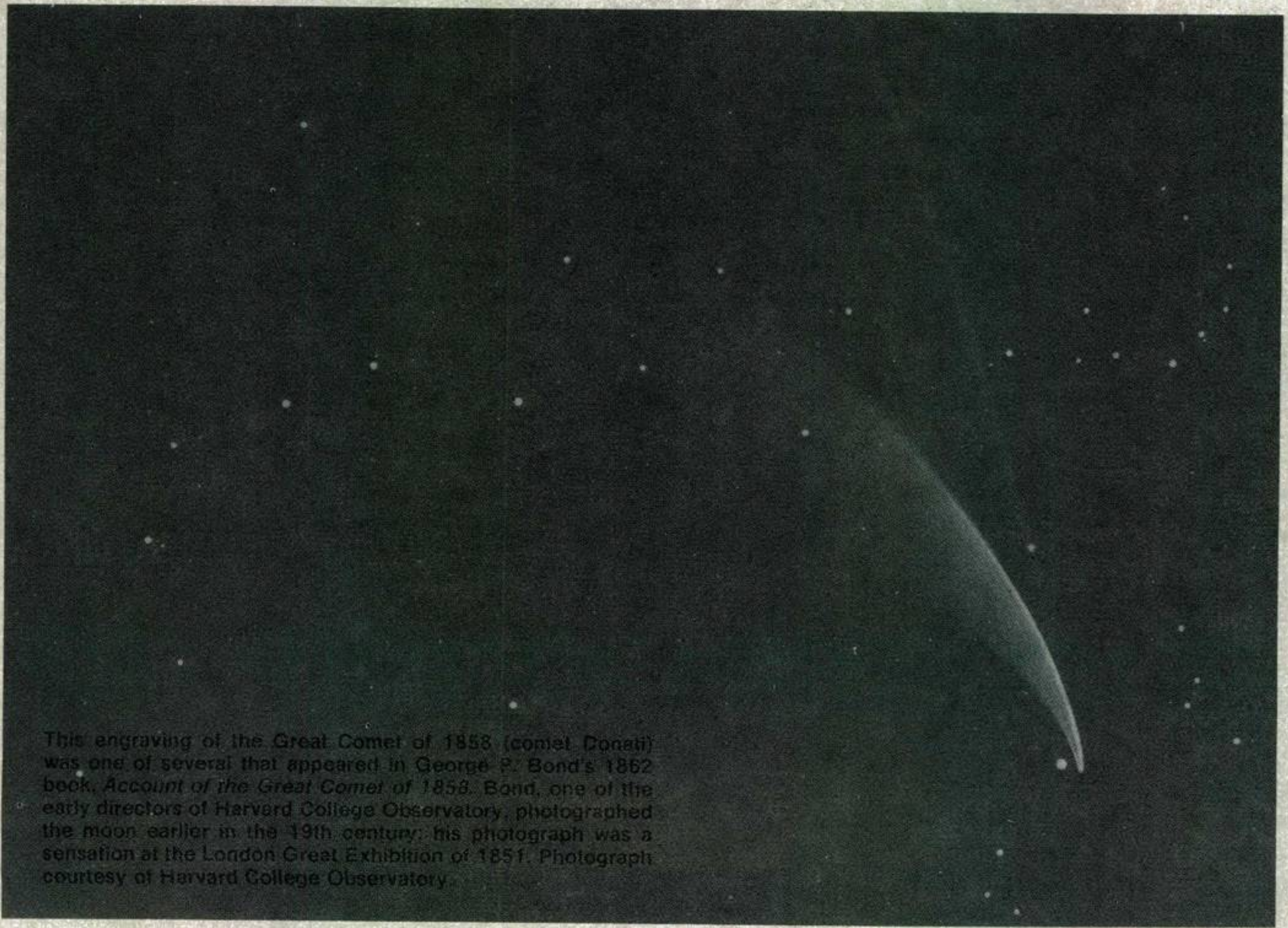
Harvard raised $3,000 to adapt Dana House as an observatory. Bond became its first director, donating both his services and instruments to the college. A cupola with a turning roof was erected on top of Dana House and a large reflector made by Short in London was installed. Bond continued as director of the Harvard Observatory until his death in 1859, two nights before the 20th anniversary of his first observations there.

Two additional observatories which appeared around 1840 were the Philadelphia High School Observatory and the West Point Observatory. One of the main figures in astronomy to come from the U.S. Military Academy during its pre-observatory days was Ormsby Macknight Mitchel (1809-1862). In 1832, Mitchel resigned his commission, and four years later embarked on a teaching career at Cincinnati College. His public astronomy lectures in 1843 so enthralled his Cincinnati neighbors that the first publicly funded U.S. observatory was built there in 1845. Mitchel's idea was to build the observatory by selling shares in the Cincinnati Astronomical Society. While director of the observatory (1845-1860), Mitchel created the first "popular astronomy" magazine in America, and perhaps in the world. It was called the **Sidereal Messenger** and survived for only two years, from 1846-48.

The First National Observatory

The observatory-building craze which found its way into so many 19th century American colleges and universities also had its effect upon the federal government. While the need for a national observatory was often discussed and indeed urged by prominent Americans, it was not until 1809 that Congress acted upon the first actual petition. The concept of building a national facility was tied to a seemingly peculiar, although unquestionably patriotic, suggestion by William Lambert, an amateur astronomer from Virginia. He proposed that the country really needed its own prime meridian — a longitude reference similar to what the Greenwich meridian was to Europe. The House of Representatives formed a select committee to consider what would be required to establish a "first meridian" through the capital. The committee sent a favorable report to the House which passed a resolution authorizing the president to do so, but nothing happened. Two years later, in 1812, Secretary of State James Monroe supported a new petition stating explicitly that "For this purpose an observatory would be essential utility." Again, nothing was built.

For the next several years, Lambert continued to petition, and the House continued to set up select committees. In 1821, he was finally authorized "to make astronomical observations . . . to ascertain the longitude of the Capitol from Greenwich." Lambert submitted his report to Congress in 1822, urging the establishment of an observatory — for



This engraving of the Great Comet of 1858 (comet Donati) was one of several that appeared in George P. Bond's 1862 book, *Account of the Great Comet of 1858.* Bond, one of the early directors of Harvard College Observatory, photographed the moon earlier in the 19th century; his photograph was a sensation at the London Great Exhibition of 1851. Photograph courtesy of Harvard College Observatory.

without one, "any attempt to compile a nautical almanac or astronomical ephemeris for ourselves would be futile, if not preposterous."

John Quincy Adams was the great champion of an American observatory during this period. In his first annual message to Congress on Dec. 6, 1825, President Adams specifically suggested that an observatory should be built; while yet another select committee was formed, no observatory followed. In 1835, Secretary of the Navy Mahlon Dickerson was asked by the House Committee on Naval Affairs about the need for an astronomical observatory. He replied, "A national observatory, although not immediately necessary to the defense of our country, is remotely so."

Now a congressman from Massachusetts, John Quincy Adams continued to lobby for an observatory with extraordinary zeal. As chairman of the select committee on the Smithsonian bequest, in 1840 Adams said, "The express object of an observatory is the increase of knowledge by new discovery. . . . There is no richer field of science opened to the exploration of man in search of knowledge than astronomical observation." With such an extraordinary friend among the Washington elite, one wonders why astronomers were not presented with the observatory of their dreams. In Quincy's own memoirs, he suggested that rival politicians contrived to oppose any measure he decided to support. That astronomy found itself a pawn in high level political infighting seems to have been the case, for in an act approved by the House on July 10, 1832, authorizing coastal surveys, the enemies of Urania inserted "nothing in this act, or the act hereby revised, shall be construed to authorize the construction or maintenance of a permanent astronomical observatory."

Adams' desire for an observatory was fulfilled during his lifetime due to some curious developments at the Navy's Depot of Charts and Instruments. Founded in 1830, the Depot's first superintendent, Lt. L.M. Goldsborough, set up what was actually the Navy's first astronomical observatory in Washington. The small circular building contained a 30 inch long transit telescope (used to observe the passage of celestial objects across a longitudinal meridian) mounted on a brick pier. Goldsborough was soon told to discontinue his work, because it was "unconstitutional" for the Navy to have an observatory. Adams' opponents had won yet another round.

In 1833, Lt. Charles Wilkes succeeded Goldsborough as superintendent. Frustrated by Congressional inaction, Wilkes built an observatory using his own funds, located virtually in the shadow of the Capitol. Observations were made there by Wilkes and his successor for nearly 10 years. In Willis Milham's account of early American observatories, he described it as a "rather flimsy building", since severe storms would often blow off the shutters and door leaving the instruments exposed. Yet, it was a bona fide observatory with a transit instrument permanently mounted and observations taken through roof shutters.

In 1836, Wilkes left to prepare for the U.S. government's first fully authorized scientific expedition. The mission was to explore and survey the Pacific and South Seas, and Wilkes was absent from the Depot, leading the expedition from 1838 to 1842. During his absence, Lt. James Gilliss was placed in charge and specifically sanctioned to begin a series of regular astronomical observations in Washington — to be augmented by a similar set to be made by William Cranch Bond at his home observatory in Dorchester, Mass. The apparatus purchased for these observations laid the foundation for the establishment of a permanent Naval Observatory — which came about on Aug. 31, 1842 when a congressional act authorized the erection of a permanent Depot of Charts and Instruments. The odd name of "Depot of Charts and Instruments" had long been a camouflage for astronomy, so soon after the building was completed (at 23rd and D Streets, N.W., a site chosen by President Tyler) it became known as the U.S. Naval Observatory. The new building was ready for occupancy late in 1844, and Lt. M.F. Maury succeeded Gilliss as its first superintendent.

The observatory craze which started in the 1830s continued unabated through the rest of the 1800s, culminating in the establishment of the great observatories in the present century. Agnes M. Clerke, writing toward the end of the 19th century, mentioned that in 1882 there were 144 active American observatories! In elaborating on such growth in 1893, she pointed out that, "Corporations, universities, municipalities, vied with each other in the creation of such institutions; private subscriptions poured in; emissaries were sent to Europe to purchase instruments and to procure instruction in their use. In a few years the young Republic was, in point of astronomical efficiency, at least on a level with countries where the science had been fostered since the dawn of civilization." It had been nearly a century earlier when orreries stood as "monuments to the reasonableness of Nature and the genius of man" in the Enlightenment. To Americans in the era of Manifest Destiny, the establishment of observatories may have seemed a tangible way of showing that the nation's spiritual horizons now extended far beyond mere continental limits to the very edges of the observable universe. It must have been particularly gratifying to John Quincy Adams to enter the last year of his life (1848) having finally seen the establishment of the U. S. Naval Observatory, as well as the recent birth of the Smithsonian Institution (1846). While it was not until 1890 that the Smithsonian's Astrophysical Observatory was founded, Adams was surely a most devoted godfather to these "Lighthouses of the Skies".

ASTROPHYSICS IS BORN: 1840-1900

The Rise of Physical Astronomy

As the United States approached the middle of the 19th century, the nation's role in astronomy began to change from that of humble student of European traditions to leader among the practitioners of the new astronomy. Once begun, American contributions continued to come rapidly and often simultaneously from different areas — spurred on by a developing technology which was to change not only the methods of astronomy, but also the course of civilization.

The invention of photography in the late 1840s was a classic case of a new technology opening a new frontier for science as well as for society. In the application of photography to astronomy, pioneering efforts at Harvard in 1850 resulted in the first photographs of stars. The modern technique of precise photographic astrometry (determination of star positions and motions by photography) began in the early 1860s when Lewis Rutherfurd of New York made the first successful photograph of a total cluster of stars — the beautiful Pleiades. He used a photographically corrected lens that gave precise images, faithful enough to provide a useful comparison with star plates taken today. We thus have a time base of over 100 years for the study of motion of the stars in this famous cluster.

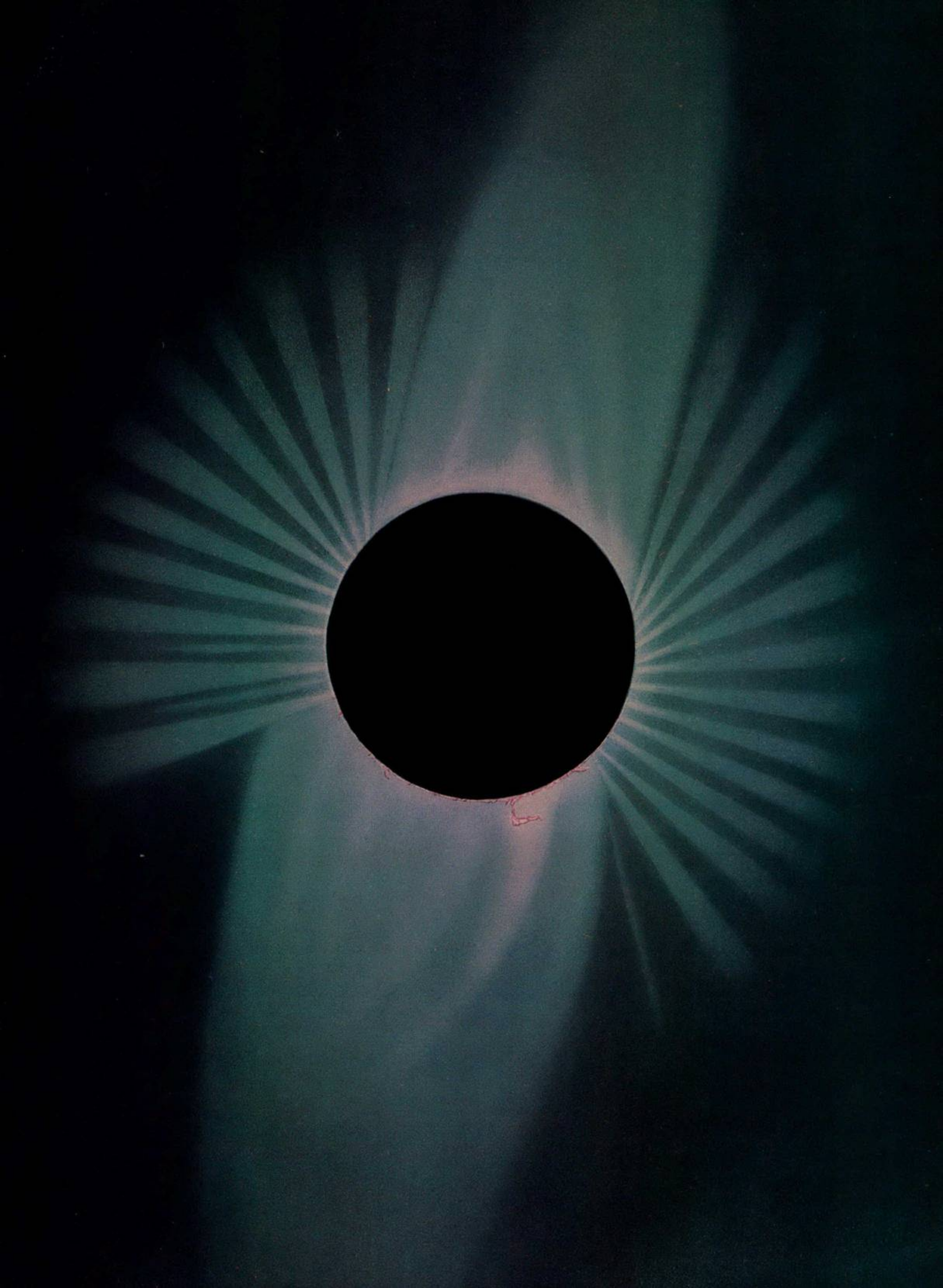
Rutherfurd was also the first American to attempt to arrange the stars into an orderly sequence according to differences seen in their spectra. This work was overshadowed by greater efforts in Europe, but still marks the beginnings of astrophysical spectroscopy which, by the turn of the century, would be a field dominated by Americans.

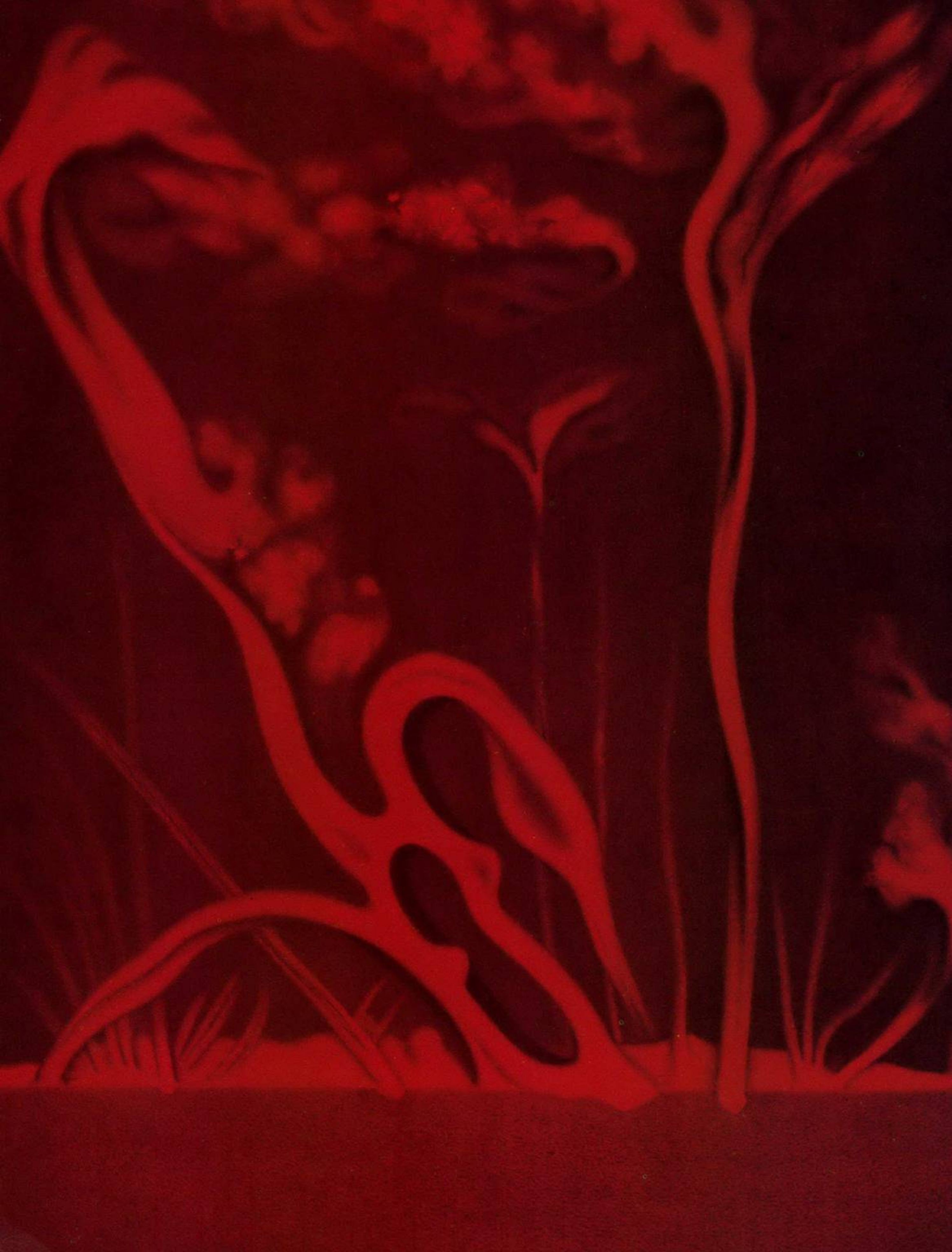
The 1860s saw the coming of the great refractors to America. We have seen that descriptive astronomy, the triumphant new astronomy of Herschel, depended upon the availability of large telescopes. The American observatory boom of the 1830s introduced descriptive astronomy to the U.S., and the rush to obtain larger and larger instruments gained momentum. Few things are as rare in science as predicting the certainty of a new discovery. During those times, however, a new large telescope would invariably lead to some sort of new discovery, and thus the idea of financing a "new giant" was often an easy one to sell.

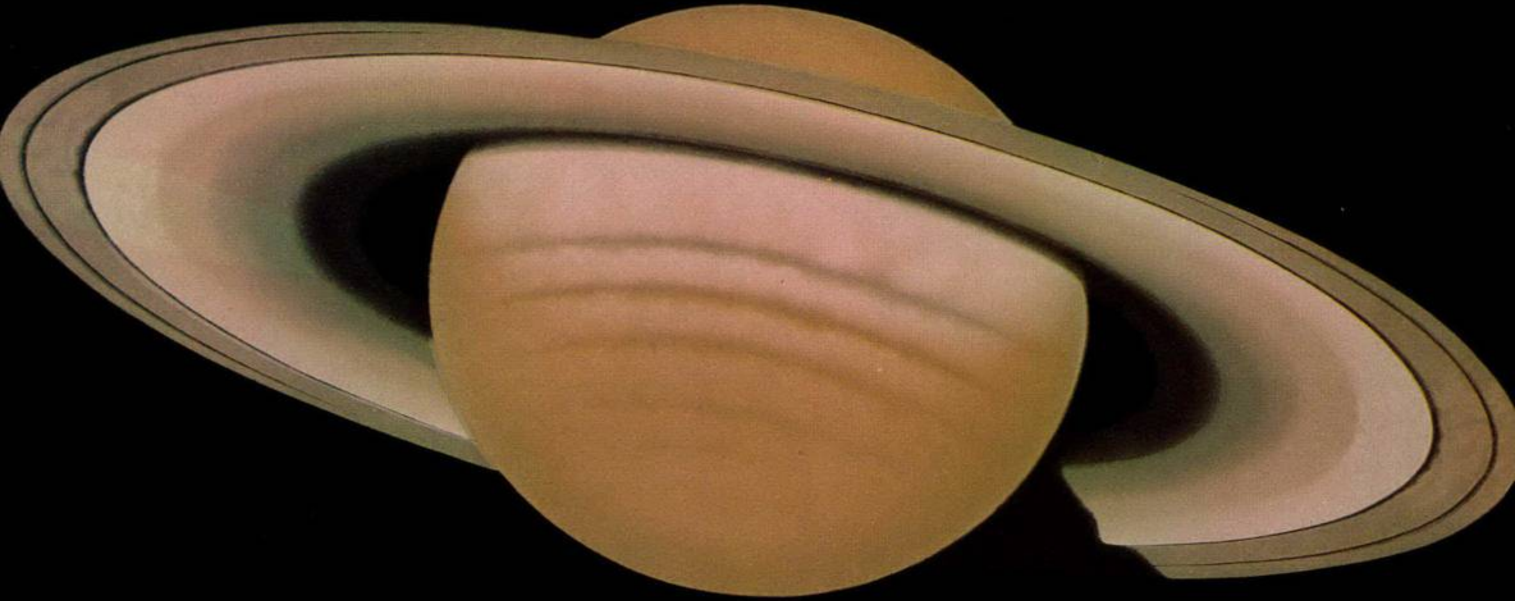
From 1844, Harvard's 15 inch telescope had ranked as one of the world's largest; but, it was only a hint of the monsters to come. In the mid-19th century, the best glass for lens making came from factories in France. The greatest opticians, however, able to hew the glass to fine optical perfection were Americans.

In the classic Massachusetts Yankee tradition, Alvan Clark grew through periods of wagon building, miniature portrait painting, printing and engraving. He had long been interested in astronomy, attending lectures when he could and corresponding with astronomers of the day. By the mid-1840s, Clark had produced several telescopes, all for his own use.

The total solar eclipse of July 29, 1878 inspired this rendering by E.L. Trouvelot, who observed the event from Creston in the Wyoming Territory. Note the row of prominences along the eastern limb of the sun's obscured disk. The row of streamers in the sun's corona are characteristic of drawings from this period. Eclipses were astronomers' only means of obtaining information about the sun until the invention of the spectroscope. Photograph courtesy of Fairfield County Astronomical Society.







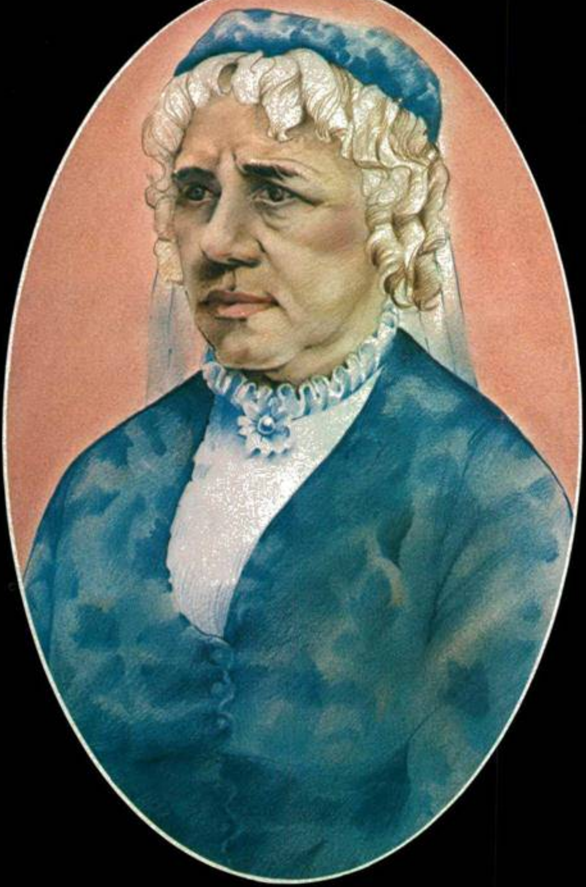
A row of "solar protuberances" (as prominences were known in the 19th century) rises like thin smoke from the edge of the sun. Before the development of adequate filters for solar observing, such objects as these could be seen only when the sun was low in the sky and dimmed by the atmosphere — which may account for their extreme redness in this drawing. One of the best drawings ever made of Saturn is seen above. Note the division in the outermost ring and the gradual dimming of the B ring toward the center, as well as the thin cloud bands on Saturn's disk. Both renderings were by E.L. Trouvelot. Photographs courtesy of Fairfield County Astronomical Society.

At the time, telescope mirrors were made out of metal — usually an alloy called "speculum" metal; they would quickly tarnish, thereby making it almost impossible to maintain reflecting telescopes. Clark's 1847 drawing of the Orion nebula, as seen through his 7-1/2 inch, greatly impressed local astronomers — notably William Cranch Bond at the new Harvard College Observatory. Clark fully realized the limitations of "speculum" reflectors and thus quickly turned to the production of lenses.

In 1860, the Clarks — father and two sons — were asked to build a refractor larger than any that existed in the world. The history of this great telescope, now at the Dearborn Observatory at Northwestern University, involved the darkest period in our nation's history, the Civil War. The telescope had been originally commissioned by the University of Mississippi, but while the 18-1/2 inch lens and scope were being completed, all communication between the Clarks and the university ceased. In 1863, members from the newly formed Chicago Astronomical Society petitioned for the lens. Harvard astronomers were interested, but the wealthy and persistent Chicago interests won out. The telescope had a wooden tube when it was mounted on the campus of the old University of Chicago in 1866. In 1911 it was remounted and continues to be used today at Northwestern. The old mounting can still be seen in the basement of the Adler Planetarium in Chicago, where it looms as a goliath among the planetarium's famous collection of telescopes and astrolabes.

The 18-1/2 inch scope was the largest in the world at the time of its completion; three other instruments made by the Clarks also were distinguished in this way. The 26 inch of the U.S. Naval Observatory, known as the "Great Washington Equatorial", was a source of true national pride. Simon Newcomb, the observatory's director, saw to it that it exceeded the next largest, the Newall telescope in England — and it did, by one inch! The first true mammoth produced by the Clarks was the 36 inch Lick telescope completed in 1888, and their final triumph was the 40 inch Yerkes completed in 1895-97 for the University of Chicago.

We can look back with pride to the legacy of great refracting telescopes built in the 19th century. The large telescopes built during the 20th century,

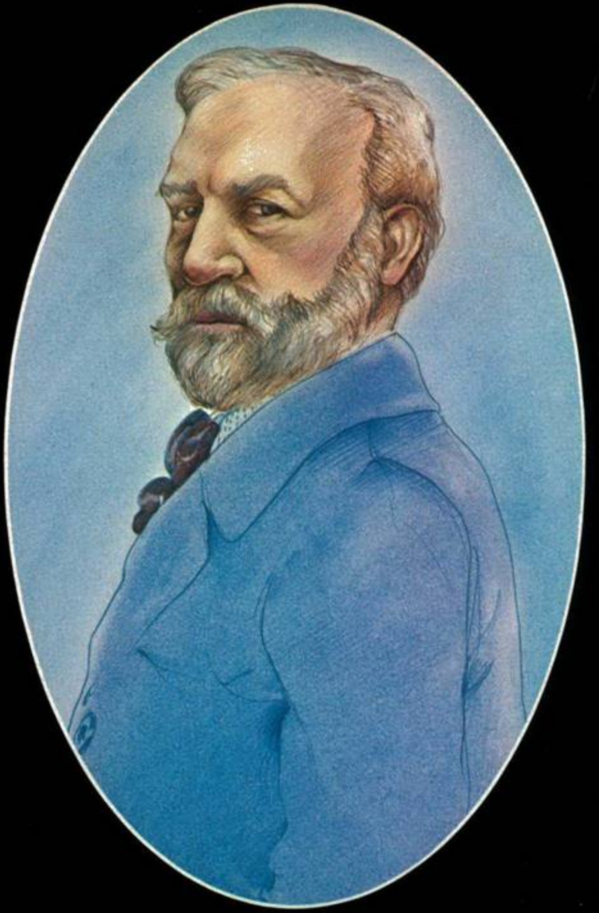


Maria Mitchell (1818-1884)

As American astronomy developed during the pre-Civil War years, Maria Mitchell became the first American woman astronomer to achieve international recognition. Her scientific training came initially from her father, William Mitchell, a Nantucket Quaker and amateur astronomer. Many of her early observations — including her discovery of a comet on Oct. 1, 1847 — were made in her father's observatory. She supplemented the knowledge gained from her father and provided her own education by extensively reading European authors.

Her comet discovery made her a celebrity (she received a gold medal from the king of Denmark for its discovery). In 1848 Mitchell was elected to the American Academy of Arts and Sciences — over her own violent protests; she was the first (and for a long time, the only) woman to be so elected. Finally, in 1865, she became professor of astronomy at Vassar.

A passionate advocate of women's rights, Mitchell noted the secretarial positions of women in observatories, and wrote indignantly, "In the half-lighted and wholly unventilated offices women work patiently at the formulae, and pile up logarithmic figures; in the open air, under the blue sky or the star-lit canopy, boys and men make the measurements!" Later, she said, "Until women throw off reverence for authority they will not develop. When they do this, when they come to truth through their own investigations . . . the truth which they get will be theirs, and their minds will go on and on unfettered."



Samuel Pierpont Langley (1834-1906)

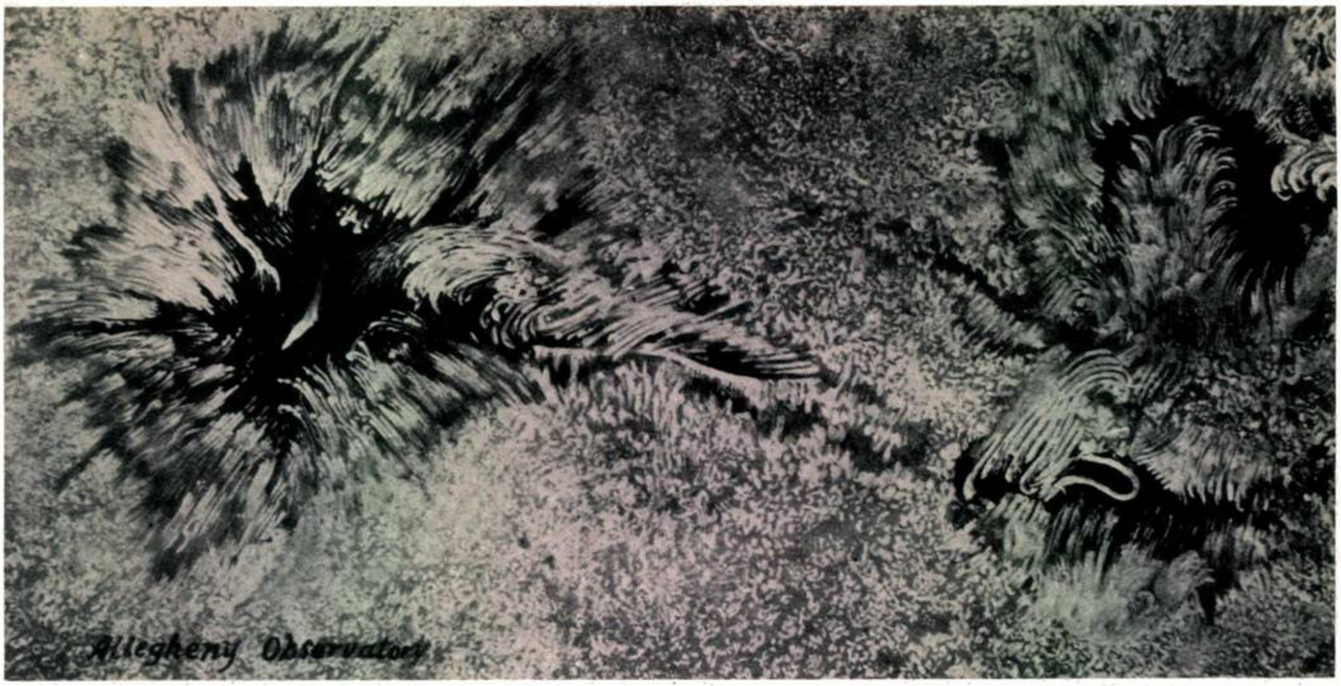
Samuel Langley was a man of diverse interests; in addition to advancing the science of solar astronomy, he was a brilliant aeronautics engineer.

Though Langley began his career as a civil engineer in Chicago, his astronomical expertise was sufficient to gain him an assistantship at Harvard Observatory. He later taught mathematics at the U.S. Naval Academy, and finally in 1867 was made director of the Allegheny Observatory in Pittsburgh.

His chief interest was the sun — specifically, solar activity and its effect on weather. In 1878, he invented the bolometer to measure the sun's radiant heat (infrared radiation). With that device, Langley was able to observe the sun's spectrum not only in visible light, but far into the infrared region.

Langley was also an early proponent of solar energy. In his book *The New Astronomy* (1889), he states, ". . . there is an immense fund of possible mechanical power still coming to us from (the sun) which might be economically utilized . . . there are startling possibilities of profit in the study of our subject."

Toward the end of his life, Langley concentrated his efforts on building a flying machine. His was the first successful heavier-than-air, unmanned flyer propelled by steam power. But, his manned machines suffered mechanical failures, the last of them in 1903, crashing into the Potomac just nine days before the flight at Kitty Hawk. Had he been able to prevent the snagging of the launch catapult, Langley might have beaten the Wright brothers to aeronautic immortality.



Samuel P. Langley's major field of study was the sun, and this drawing is one of many that he prepared of sunspot groups. Compare this rendering with that by E.L. Trouvelot on page 22; Trouvelot's is more colorful and fanciful, while Langley's is more dramatic and a truer representation of sunspots' actual appearance. Photograph from *The Sun and the Welfare of Man* by Charles Greeley Abbot, courtesy of Smithsonian Institution Press.

however, were not refractors, for the technology needed to place reflective coatings on glass mirrors was, by then, understood. Thus, in 1907, the 60 inch reflector at Mount Wilson was completed, followed by the 100 inch in 1917. In 1948, the 200 inch telescope was first pointed toward the skies from atop Mount Palomar. Since that time, many telescopes in the 100-inch-plus class have been built. Lick boasts a 120 inch, and our national observatory, Kitt Peak, has just completed a 158 inch.

To fully understand why America has gained such a fine legacy in astronomy, we must ask the question: Why were these telescopes built here? No doubt the Clarks were excellent telescope makers, but they were not unique, and throughout the 19th century, the glass for telescopes had to come from Europe. So, why here? The answer is not simple, and in some respects still needs to be researched by historians. There are several milestones that do stand out, however, and their importance seems certain enough to warrant review.

In the year of John Quincy Adams' death, gold was discovered in California. This event in our history not only helped stimulate the western migration that built our country, but it made the fortune of a man who had anticipated the great western wave — James Lick.

Arriving in early January 1848, Lick amassed a great fortune through land speculation. In 1873, in his 70s, he capped an eccentric career by deciding to will his wealth to the people of California. The trust was to be administered by a distinguished board, and a portion was to be expended in the construction of the world's largest telescope.

How or why Lick decided to have a telescope built in his honor is not known. It has been said that Lick's first impulse was to erect a pyramid in his memory on Market St. in downtown San Francisco. George Davidson, head of the California Academy of Sciences, and Joseph Henry, Secretary of the Smithsonian Institution, were apparently quite influential in urging him to consider the creation of a great telescope.

Construction of the observatory began in 1879 and was a prodigious undertaking for world astronomy. In January 1887, James Lick's body was removed from San Francisco and placed within the base of the 36 inch refractor. Even though pictures survive of the ceremony and long accounts of the activities were written at the time, rumors persist that the grave is empty. Other rumors hint that a construction worker is buried in Lick's place and that other workers were buried in the walls of the building. It is a sad historical note that the Chinese laborers used in the construction might have suffered the same fate which befell the builders of pharaoh's tombs, and that James Lick did indeed get his pyramid!

The first observations at Lick were made in January 1888, after several weeks of poor weather and last minute modifications to the telescope's mount. It was soon evident, however, that all the frustration was worth the view. Quite fittingly, Lick Observatory later established a public "open night" series in the summer months to allow nonprofessionals the chance to view directly the wonders that James Lick dreamed of.

Scientific accomplishments were not long in coming. James Keeler, the only member of the staff trained in the newly coined "astrophysics", designed and constructed powerful spectroscopic equipment for the 36 inch refractor. The old term, descriptive astronomy, was gradually being changed into the concept of physical astronomy — the study of the nature and physical makeup of nebulae, comets, stars, planets and novae. At the time, the composition of nebulae and their temperatures were highly debated questions. Observational evidence from Lick was soon much in demand from astronomers throughout the world who were discussing these problems. Even though the important questions were not settled immediately, Keeler's work at Lick was considered definitive, and its existence provided a much needed base from which further work was possible.

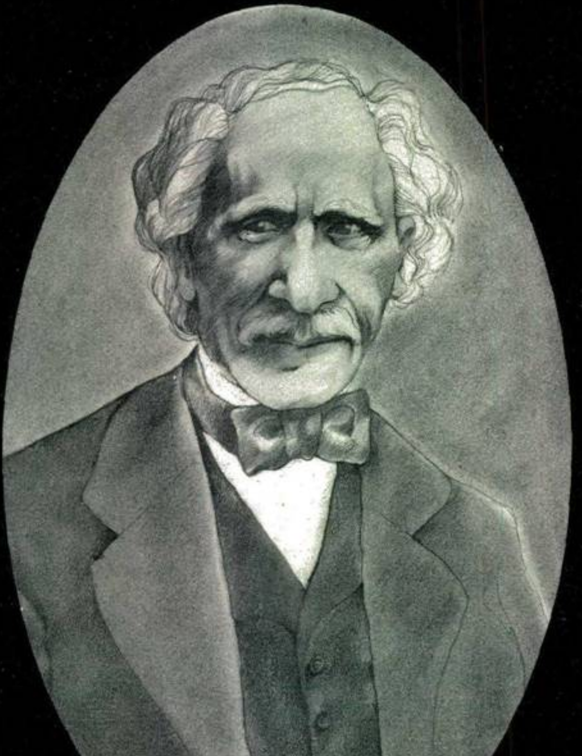
Using the Lick refractor in 1892, Edward Emerson Barnard, the renowned self-taught astronomer from Tennessee, rapidly astounded the astronomical world by discovering a fifth satellite of Jupiter — the first discovered since the time of Galileo and the one Gov. John Winthrop undoubtedly thought existed back in 1664.

In the years following its opening, the Lick staff was as turbulent as it was productive. Keeler left in 1891, and others left to join George Ellery Hale at the University of Chicago where, through the entrepreneurship of Hale, the largest lens produced by the Clarks was to be mounted for astronomical use.

Born in Chicago in 1868, Hale is revered today as the creator of three great observatories: Yerkes, Wilson and Palomar — the latter two now combined in tribute as the Hale Observatories. His legacy extends far beyond observatory building, for he also founded the **Astrophysical Journal** at the turn of the century and was a continuous force of good will in the development and maintenance of the world's scientific communities.

In the 1880s, astronomy might have languished if a link between the problems of astronomy and experimental techniques of the physical laboratory had not been found. Hale's many contacts with the leading astronomers of the day convinced him that the sun was the obvious link. The wonders that must occur on the surfaces of all stars — spots, flares, prominences — must in some way, Hale reasoned, be represented by those phenomena seen on the solar surface.

In his pursuit of the new "astrophysics", Hale was deeply influenced by early visits to the Harvard College Observatory. With generous private funding, the observatory was engaged in studies of the brightness and spectra of stars on a scale far greater than anything Hale or the world had ever seen before

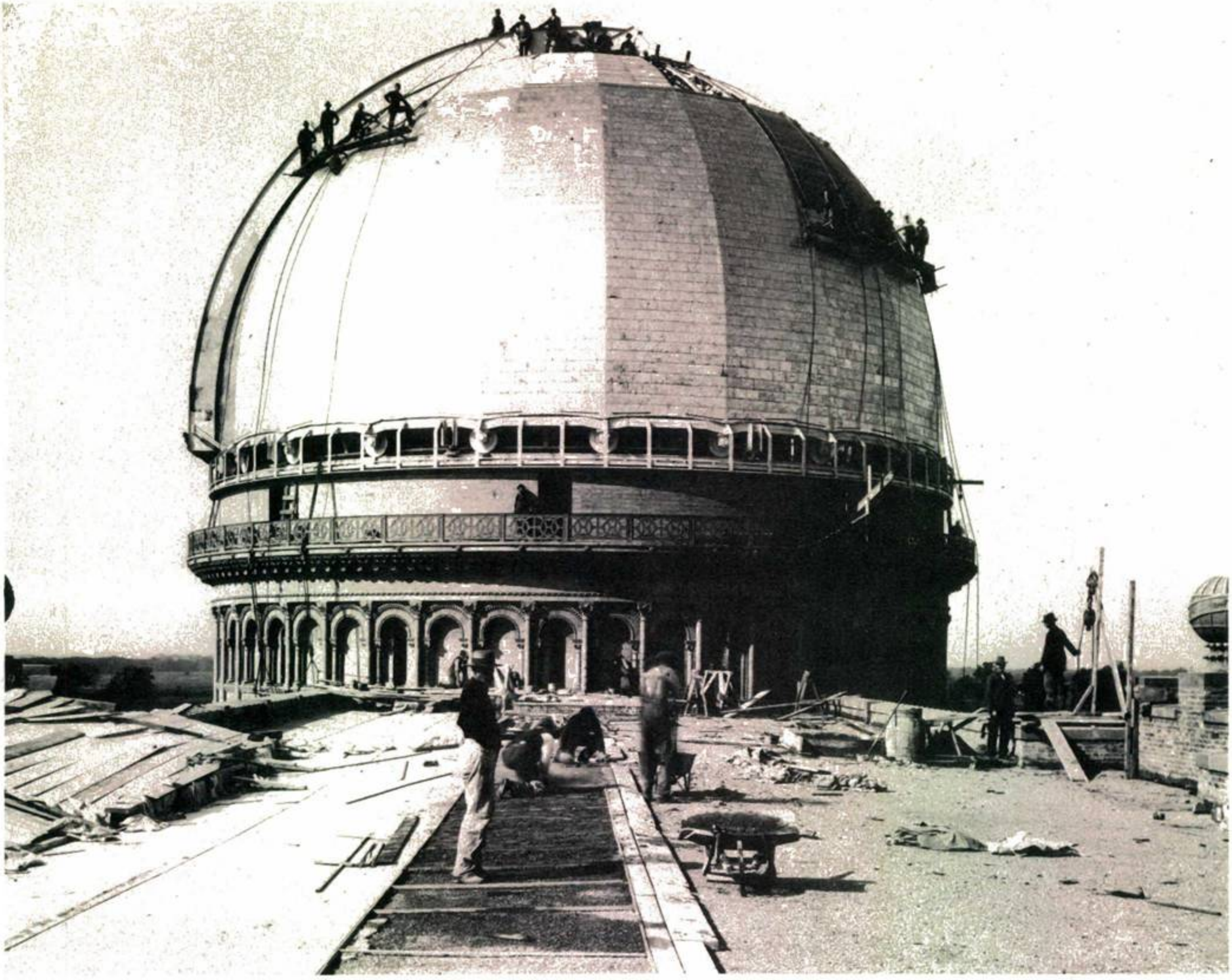


Alvan Clark (1804-1887)

Determination to succeed by sheer dint of effort — a typical "Yankee" trait — is exemplified in the life of Alvan Clark. Born in Ashfield, Mass., Clark began his career as a portrait painter and engraver, and didn't develop an interest in optics until he had reached middle age. Clark's sudden new interest was incompatible with his current occupation: He simply lacked the time necessary to concentrate on both. Therefore, he courageously closed his art studio and devoted all his time to mastering the very different art of lens engraving.

By 1846, Clark had progressed far enough in his new field so that he could open the firm of Alvan Clark & Sons in Cambridge, Mass.; they were the first producers of achromatic telescope lenses in the United States. The firm faced stiff competition from European manufacturers, and did not become financially sound until after the sale of several lenses to English buyers in the late 1850s.

The breakthrough came in 1862 with a unique father-son discovery. Clark had completed an 18-1/2 inch lens — the largest in the world to date. During the lens's testing, Clark's son Alvan Graham observed for the first time the white dwarf companion to Sirius. This success brought both honor (the Lalande Medal of the French Academy of Sciences was awarded Alvan G.) and, more important, sales. Clark refractors soon became the mainstay of the major observatories.

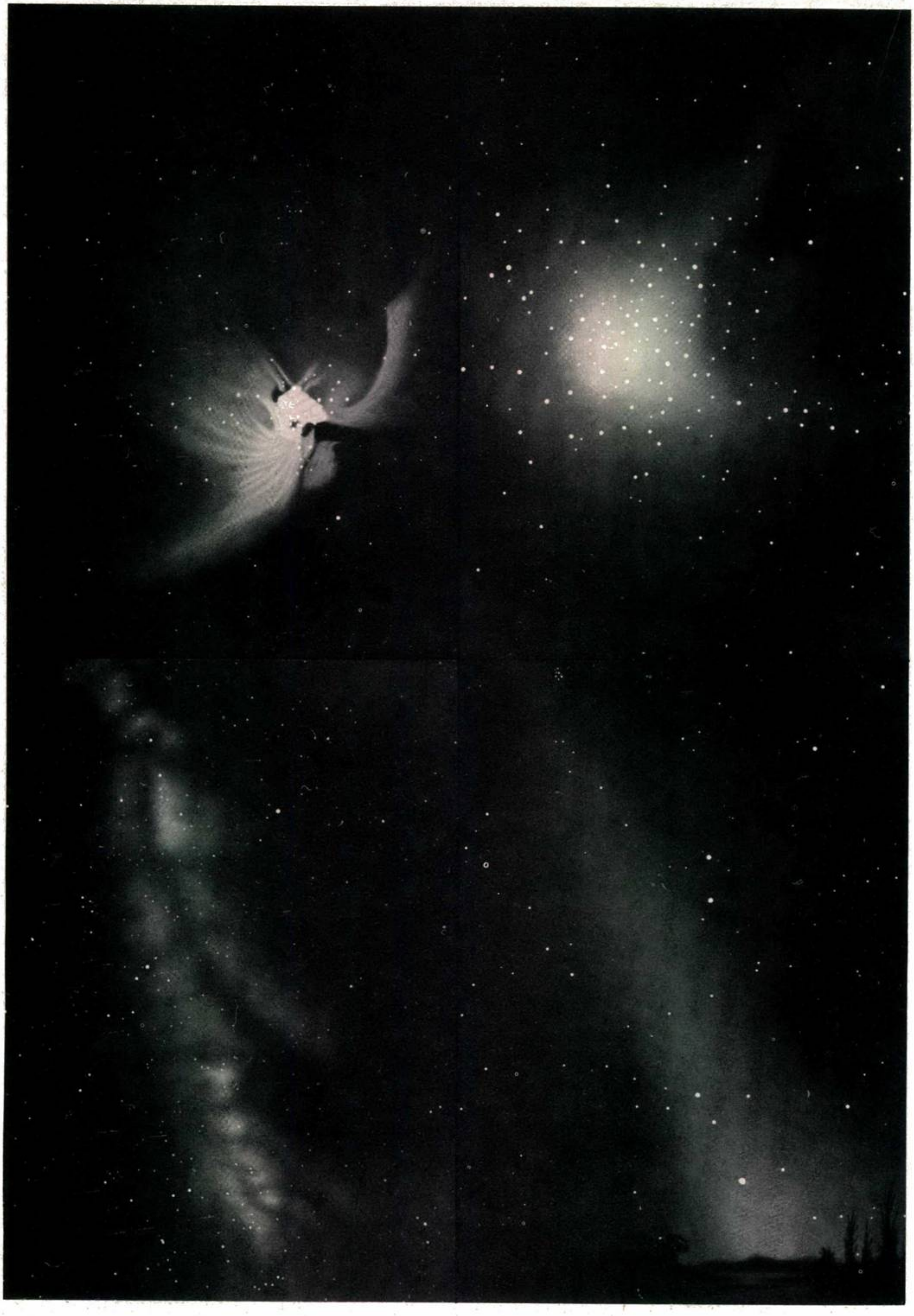


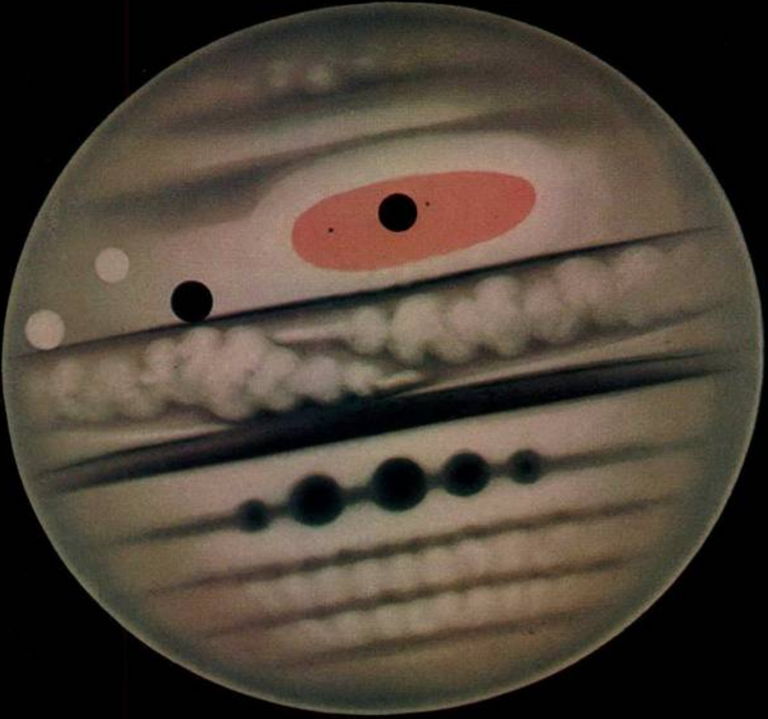
This photograph, taken in the mid-1890s, is of the construction of Yerkes Observatory. Several groups of workmen are finishing the dome, which was soon to house the largest refracting telescope in the world, with a 40 inch lens built by Alvan Clark & Sons. Organized by George Hale, Yerkes Observatory was the last major observatory to depend on a refracting, rather than reflecting, telescope. Yerkes Observatory photograph.

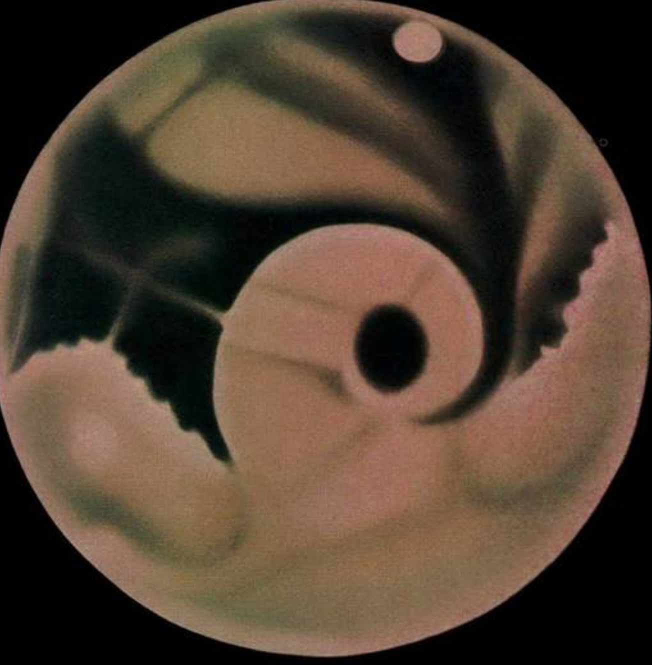
— truly the new astronomy! Its dynamic director, E.C. Pickering, had organized a large team to catalog the brightness and spectra of every star accessible to his equipment. By the late 1880s it was clear that a study of the light output of the stars, coupled to a thorough examination of their spectra, was of greatest importance. While the past 20 years had shown that stars could be classified according to their spectra, it was far from obvious what those classification systems meant. The great problem was simply that not enough spectra had been examined to create a reasonable statistical sample for analysis. When selected stars were spectroscopically examined and compared to laboratory spectra of elements in various combinations and physical states, almost any sequence could be created. Pickering strove to change this, or at least this was the effect of his work. He chose to classify as many stars as possible on the basis of the character of their spectra alone. The women who performed the incredibly detailed and enormous tasks that were essential to this project comprised an able, dedicated and enthusiastic group of associates. Pickering's female staff created an astronomical dynasty by providing the teaching and research faculty at such institutions as Radcliffe, Vassar, Wellesley, Mount Holyoke and Smith.

The contributions of Annie J. Cannon and Antonia Maury were particularly significant. Cannon created the major classification system that is the basis of those in use today, while Maury contributed a highly sophisticated classification scheme for bright stars that noted slight changes in spectral line intensities — changes that within a few decades were to receive the critical attention of the world's astronomers. By the turn of the century, for example, Dutch astronomer Ejnar Hertzsprung was convinced that Maury's subtle criteria revealed that stars were not all of the same size and brightness, but rather that "among the fishes of the sea" there also existed "whales". Hertzsprung's "whales and fishes" refer, of course, to the giant and dwarf stars of today.

To Hale, Pickering's work must have been of great interest, but certainly the greatest stimulation was the observatory itself. His infatuation with







In a preface to a volume of his drawings, E.L. Trouvelot wrote: ". . . products [of photography] are in general so blurred and indistinct that no details of any great value can be secured. A well-trained eye alone is capable of seizing the delicate details of structure and the configuration of the heavenly bodies." These words were written just a few years before photography broke free of its previous limitations, but such a master of his art as Trouvelot was can never be rendered obsolete. Depicted on these pages are the Orion nebula, the globular cluster M-13, the summer Milky Way, zodiacal light, and the planets Jupiter and Mars. Photographs courtesy of Fairfield County Astronomical Society.

observatories was to dominate his life and greatly affect the course of astronomy.

Hale's first observatory, the Kenwood Physical Laboratory, was devoted to studying the link between physics and astronomy — the sun. Built with his father's funds on family land in Chicago, its prime instrument was a 12 inch refractor, equipped with an instrument designed to study the surface of the sun as seen in the light of its characteristic elements. This fascinating device was of his own design, and he called it a "spectroheliograph". With it, prominences became easily visible without the need for a solar eclipse.

Hale reported his work in both the popular and technical journals of the day, and by his travels throughout America and Europe, began to knit together a circle of workers with common interests in studying the sun. One of Europe's leading astronomers, Sir William Higgins — revered as a founding father of astrophysics — would, in the following two decades, turn many times to his American friends for definitive spectroscopic observations that would help to prove his many hypotheses concerning the nature of nebulae and the composition of the sun and stars.

One hundred years earlier, Lalande had been able to point to only a single American observatory which fell into decay shortly after Rittenhouse's death. An additional 50 years had to pass before the most rudimentary but permanent observatories began to appear. But now, in 1892, as Hale outgrew Kenwood and accepted an appointment to the new University of Chicago, American astronomers began to emerge both as leaders of the new astrophysics and sources of the finest observations available to astronomers abroad.

In Chicago, Hale quickly began plans for a truly great telescope. Alvan Clark had ordered two 40 inch lens blanks for the University of Southern California's attempt to outdo Lick Observatory, but the school lacked financial backing and had to back out of the project. Hale seized the challenge and approached the one man in Chicago who could finance the project: Charles Yerkes, a wealthy builder of transportation systems. Only a single meeting was necessary to get Yerkes to agree to finance the great telescope — Chicago's attempt to "lick the Lick".

Spectroscopy: The Big Breakthrough

The light that we receive from stars tells us a great deal about them: their temperature and composition, their velocities relative to Earth, rotation speeds, and (indirectly) their masses and much about their formation and history. But we can get this information only through the use of spectroscopes, and through laboratory application of the data obtained.

Sir Isaac Newton, the English physicist, discovered that light was composed of different wavelengths, but the spectrum he formed was fuzzy and impure. Early in the 1800s, the German Joseph Frauenhofer, using much more sophisticated apparatus, discovered several hundred fine lines in the sun's spectrum — wavelengths where light was missing! These lines, named after their discoverer, went unexplained until the late 1850s, when the Germans Gustav Kirchoff and Robert Bunsen discovered the laws by which light is absorbed and emitted by solid and gaseous matter. Basically, they found that heated solids emit radiation at all wavelengths, while hot gases give off only certain wavelengths. But a hot gas situated before a more intense light source containing all wavelengths absorbs and removes the light at the wavelengths the gas would normally emit. Kirchoff and Bunsen also found each type of atom or molecule had a distinct pattern of lines by which it could be uniquely identified.

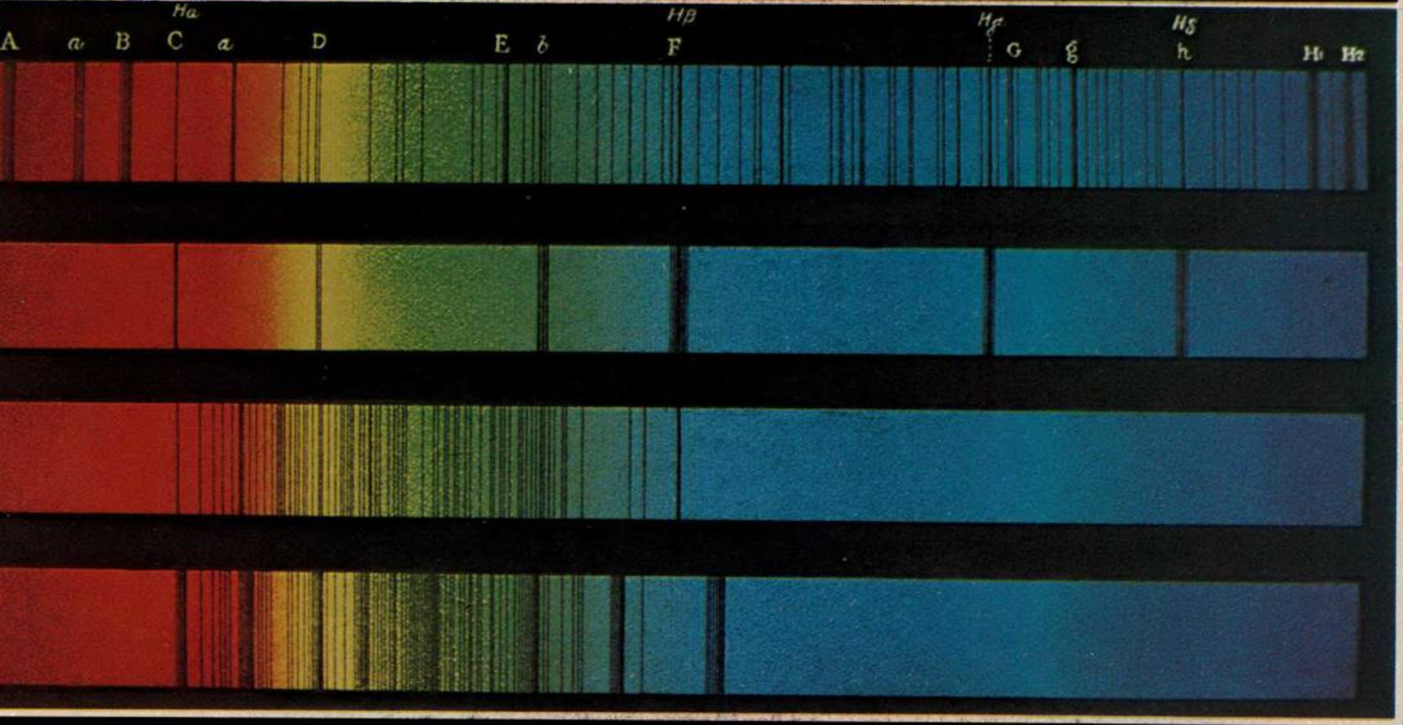
Two fruitful lines of scientific investigation followed: the study, by the light they emit, of atoms and their structure, and the study of the compositions of stars and other celestial bodies from the lines in their spectra. During the next few years, many common elements on Earth were identified on the sun, including hydrogen, sodium, iron, calcium and nickel. In fact, the element helium was found spectroscopically on the sun years before its discovery on Earth in 1895. Many astronomers soon realized that the sun had to be gaseous and must increase in temperature with depth.

William Huggins, a British scientist, made detailed studies of stellar spectra and detected many of the terrestrial elements on other stars. Huggins also exploited the Doppler shift (a change in wavelength of Frauenhofer lines, produced by an object's motion relative to Earth) to measure Sirius' speed of recession — a measurement that made the crucial third dimension of space open to investigation (stellar motions could previous be measured in only two dimensions). In addition, the Italian Pietro Angelo Secchi first divided the stars into major spectroscopic classes (his Types I, II, III and IV).

American scientists soon began making their mark in the new field of spectroscopy. Lewis Rutherfurd made advances in instrumentation and found that spectra of other stars differed greatly from the sun's spectrum. Henry Draper made careful measurements in the laboratory of many elements' wavelengths. By 1872, Draper had taken photographs of many stellar spectra with his telescope. After his death, Draper's widow donated enough money to Harvard University to permit the extensive classification of the spectra of all the brighter stars in the sky. The job, begun in 1887, eventually included more than 225,000 stars. The stars were classified by the O, B, A, F, G, K, M, R, N, S system still used today — basically a classification of stars' surface temperatures based on the elements most prominent in their atmosphere, as revealed by the spectroscope.

Today, spectroscopy is one of astronomy's most important tools; sensitive films and ultra-sensitive television sensors can obtain spectra of objects too faint to be seen through a telescope. Spectrographs on board satellites can probe wavelengths invisible to the eye — wavelengths that can't penetrate Earth's atmosphere, but reveal things visible light cannot. Much of our understanding of the universe comes from spectroscopic observations of distant galaxies and still more distant quasars; while within the solar system, our knowledge of the composition of the planets' atmospheres, the tails of comets, and the sun and its atmosphere all derive from spectroscopy.

Upper: Photograph by Michael Mendillo.
Lower: Drawing from *The Story of the Heavens*, by Sir R.S. Ball.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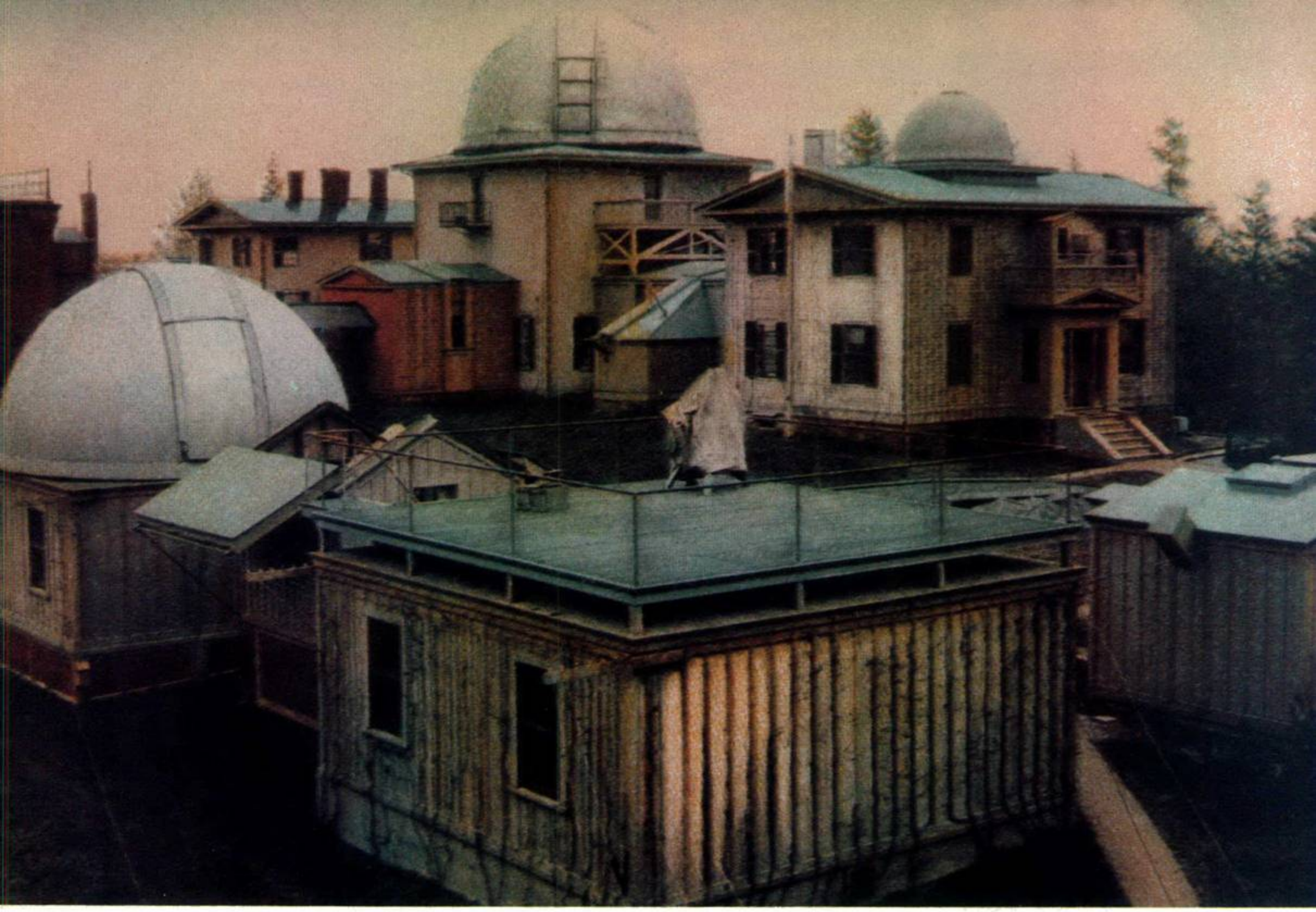

This turn-of-the-century photograph of Harvard Observatory in Cambridge, Mass., provides a good overall view of the building of which the observatory consisted. The Harvard Observatory was the foremost institution of its kind in the United States for much of the 19th century, and many of America's most important astronomers received training there. Photograph from the Parkhurst Postcard Collection, courtesy of David DeVorkin.

Hale's dream of a physical laboratory equipped with instruments capable of detailed measurements of the sun and stars went far beyond Yerkes' imagination. Not to be frustrated, Hale found other funds in spite of a great economic depression in the Chicago area. Even before the great 40 inch instrument was officially dedicated, preliminary tests revealed a new companion to the star Vega, dramatically attesting to the fine definition and clear dark field of the new telescope. In 1899, the telescope's spectroscopic equipment was finally completed; within only one year, it yielded more information about the surface of the sun and its atmosphere than had any previous instrument.

Hale, incessantly seeking clearer skies and larger instruments, left Yerkes in the first years of the 20th century. He set himself the task of pursuing those who could fund his new dreams: John D. Hooker, Andrew Carnegie, the Rockefellers and others. Soon he succeeded in establishing a new mountain observatory in southern California — the Mount Wilson Solar Observatory. At first his prime instrument was a large horizontal telescope used for examination of the sun, but within a few years, Hale designed a vertical telescope for solar studies. The first was 60 feet high, and the second over 150 feet high; the new design greatly improved the stability of the solar image, for it was not as affected by atmospheric turbulence and temperature problems as earlier designs were. As the years progressed, a 60 inch reflector was erected; then, with World War I raging, the 100 inch Hooker reflector was completed — destined to be the largest in the world for many years. No sooner had the 100 inch been put into operation than dreams for an even larger instrument began. In the notebooks of Francis Pease, one of the dedicated men summoned by Hale to Mount Wilson, can be seen plans for the 200 inch, and even a 250 inch — as early as 1921.

In many respects, Hale's vast accomplishments at observatory building masked his own zeal for getting at the fundamental questions asked by astronomers. In the following sections, we will consider some of the major problems that confronted astronomers at the turn of the century, and see how much of the progress that led to their solution came from American efforts.

Practical Astronomy in Late 19th Century America

A major emphasis of astronomy in post-Civil War America was its practical application to the determination of time and position — the art of navigation. At the Nautical Almanac Office in Washington, D.C., Simon Newcomb was able to utilize his genius for the observational, theoretical and practical sides of celestial mechanics — the application of mathematical techniques to the physical study of the motions of the moons and planets. Newcomb created a gigantic table of the positions and motions of the sun and planets as seen from any given point and time on Earth's surface. As Nathaniel Bowditch would have well appreciated, this type of information was indispensable for navigation.

Following in Bowditch's tradition, Newcomb's goal was to create the world's most precise reference text by utilizing every available piece of observational data on planetary motion, together with an improved gravitational theory which included the effects of the giant planets Jupiter and Saturn. The theory which Newcomb used for the effects of Jupiter and Saturn upon the overall gravitational structure of the solar system was worked out by George W. Hill — a task which took the full decade of the 1880s to complete.

Hill's greatest legacy to astronomy was that, in the process of computing how the moon's observed position might deviate from its predicted position, he developed a new form of mathematics that was eminently practical in the solution of such complex problems. His goal was not mathematical elegance, but rather the practical applicability of mathematical techniques. He began a tradition practiced by American mathematical astronomers and astrophysicists that allowed them in the following half century to make tremendous strides which would have been greatly hampered had mathematical elegance remained a constraint. Astronomers of the 1950s were to find that Hill's mathematical methods were highly suited for use in high speed electronic computers. Astronomers at Yale and the Naval Observatory teamed with researchers from IBM to create the first major application of computer technology to the solution of astronomical problems — a tremendous refinement in our knowledge of the positions and motions of the outer planets in the solar system.

During Newcomb's long tenure at the Nautical Almanac Office, he addressed many of the practical problems which involved astronomy and public affairs. In the 1870s and 1880s, nearly every railroad, state and major city kept its own time, and navigators at sea were free to define the beginning and end of the day as they pleased. Newcomb devoted much of his time to settling these international aspects of "mundane" astronomy. The system of Standard Time Zones and the necessity for a Universal Time were problems all worked out during Newcomb's lifetime.

Americans were not only interested in the sun for the purpose of keeping time, but also for the amount of energy received from it by Earth. In America, the sun's light and heat were closely scrutinized by Charles Augustus Young of Dartmouth and Princeton, and Samuel Pierpont Langley of the Smithsonian Astrophysical Observatory.

Langley was four years old when, in 1838, the establishment of an astronomical observatory was considered by John Quincy Adams a fitting way to partially carry out the wishes of the James Smithson bequest. Fifty-two years later, the dream became a reality under Langley's direction. Joseph Henry, one of Langley's predecessors, had greatly aided the establishment of the observatory by supporting astronomical research. Such efforts, however, were not successful until Langley, in 1887, convinced Congress that an American astrophysical observatory was needed to pursue the new astronomy. Langley then left the Allegheny Observatory to become the third Secretary of the Smithsonian, and set up a small observatory on the grounds of the Smithsonian Institution in Washington.

Langley's contributions to astronomy included the precise determination of the intensity of the sun's radiation and its distribution over a broad band of the spectrum. To aid in this work, he invented a solar energy collector called a bolometer. In the following 50 years, work with the bolometer was continued and solar study expeditions to different parts of the world were sponsored. Charles Greeley Abbot, Langley's successor at the Smithsonian, observed solar eclipses from Pike's Peak and set up solar intensity monitoring stations in California, Chile, Egypt, and other parts of Africa; he also prophetically lobbied for application of solar energy to the needs of a rapidly growing industrial society.

Langley showed from his own measurements that more than one horsepower could be gleaned from a solar energy collector only one square yard in area, if the conversion to mechanical energy was complete. He also showed that if a solar energy collector the size of Manhattan Island could be built, it could generate enough energy to drive all the steam engines in the world. Langley was also interested in solar engines already in operation in France and the U.S., and was concerned with the limitations of Earth's own energy supply of coal. In his book, **The New Astronomy**, he wrote, "Whoever finds the way to make industrially useful the vast sunpower now wasted on the deserts of North Africa or the shores of the Red Sea, will effect a greater change in men's affairs than any conqueror in history had done . . . where man no longer shall worship the sun as a god, but shall have learned to make it his servant."

The Smithsonian Astrophysical Observatory was transferred from Washington to Cambridge in 1955, and became associated with the Harvard College Observatory. The organization was largely responsible for the success of the International Geophysical Year at the end of the 1950s, and continues today to be an international clearing house for reports and announcements of astronomical events.

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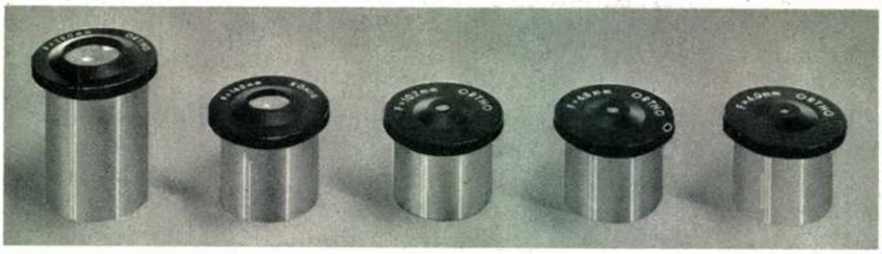

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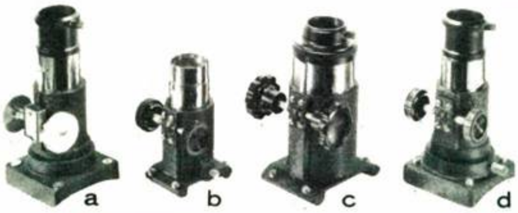

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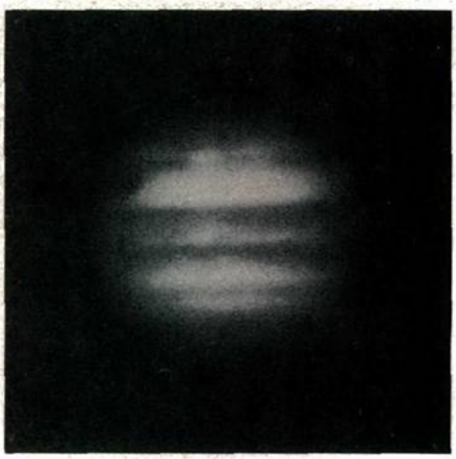
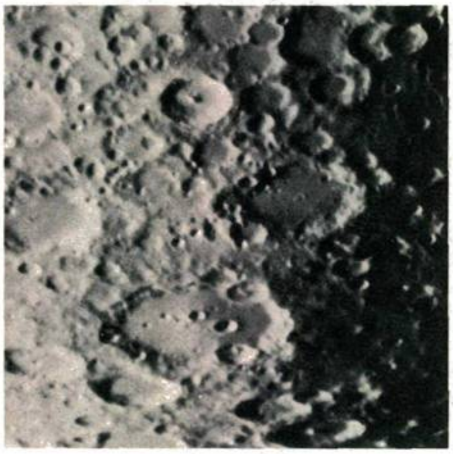

Jupiter's Cloud Belts


Clavius and Tycho

The Crab Nebula

The Ring Nebula

Open Cluster M 11

Galaxy NGC 253

The Orion Nebula

The Horsehead Nebula

The Omega Nebula

A Special Thanks

to the Celestron 8 owners who have shared these fine photographs with us. We reproduce them here as a source of inspiration for all who aspire to excellence in astrophotography.

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History of Astrophotography

by
Trudy E. Bell

"We can hand down to our successors a picture of the sky locked in a box. What would we not give for such a record bequeathed to us by Hipparchus or by Galileo!" exulted Edward S. Holden, the first director of Lick Observatory, in his article "Photography, the Servant of Astronomy".

Holden's article appeared in 1886, when the art of photography was a mere 46 years old. Coincidentally, celestial photography was the same age; the camera had been turned skyward as soon as photographic techniques were born. Holden's article appeared during the middle of the United States' Gilded Age; the West was no longer a woolly frontier, and lusty San Francisco was vying with more cosmopolitan New York for cultural recognition.

For astronomy, it was a unique time, exciting and in dynamic flux; a time when astronomy was suddenly becoming "big science". Some of the best telescope makers were Americans with worldwide reputations: Alvan Clark and his sons, Warner and Swasey, John Brashear and others. Public lectures in astronomy were enormously popular. More than one citizen collective, fired up by a new comet or by a liquid-tongued orator, banded together to raise money by public subscription for an astronomical observatory. As fast as millionaires were making their fortunes in steel, railroads, streetcars or land, they were erecting monuments to themselves — and these monuments frequently took the guise of observatories. Moreover, each observatory was successively intended to house the largest and best telescope in the world.

Until photography came along, astronomy in

Evolution of Film Sensitivity

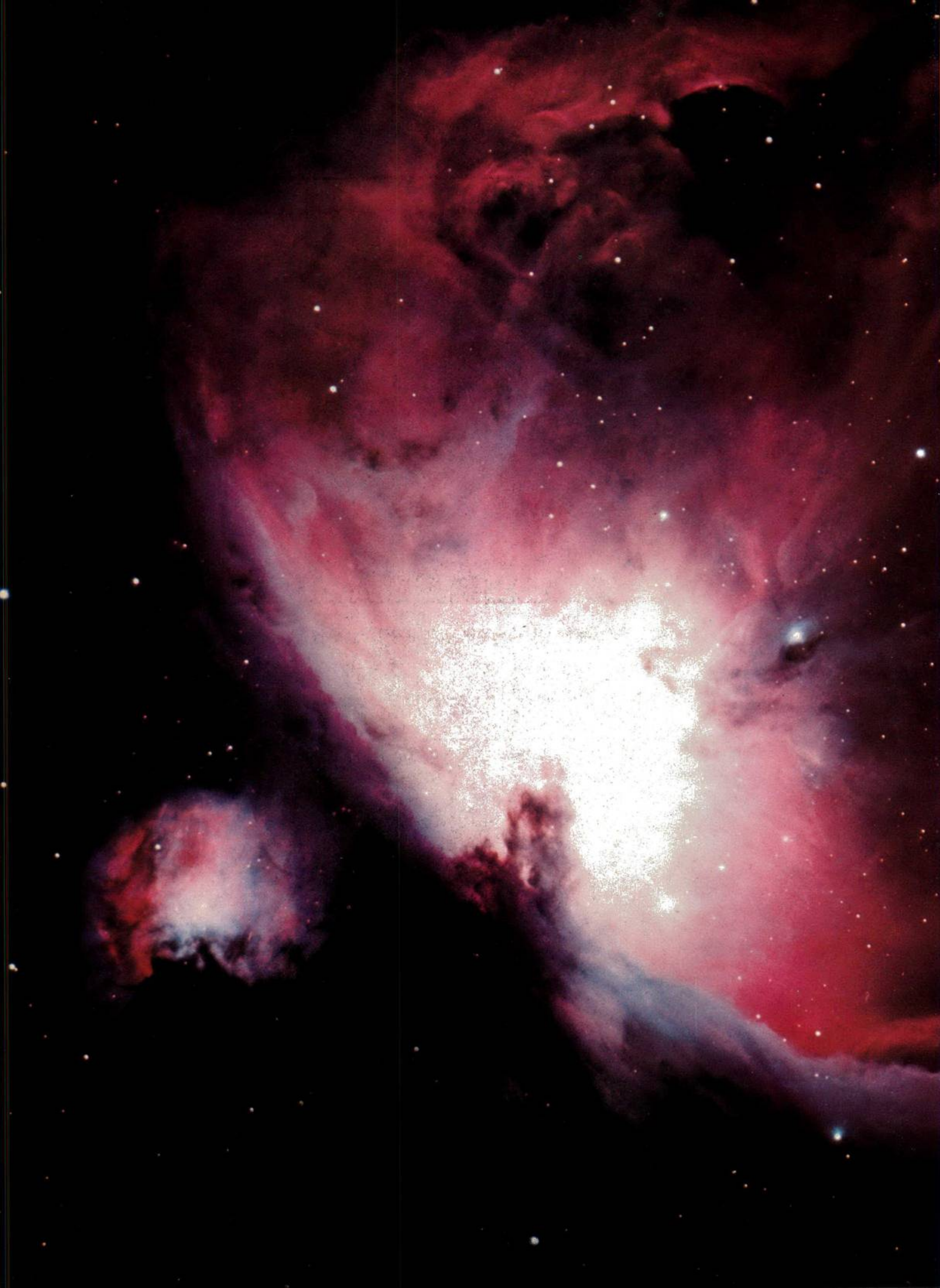
Period	Process	Sensitivity*
1839 - 1851	Daguerrotype	0.1 - 10
1851 - 1871	Wet collodion	50 - 100
1871 - 1887	First silver bromide emulsion	500 - 2.000
1887 - 1939	Modern silver bromide emulsion	2.000 - 10.000
1939 - 1959	Fastest presensitized emulsion	10.000 - 30.000
1959 - Present	Image intensifier tube	100.000 - 1.000.000

*(arbitrary units, not ASA rating)

The Andromeda galaxy (M-31), 2.5 million light-years away, is our nearest major island universe. Two dwarf companion galaxies of M-31 appear in this photograph: M-32 (below and to the left of M-31) and NGC-205 (above and to the right of M-31). Astronomers used photography to measure luminosity variations of several Cepheids in M-31; that information gave them a yardstick to measure the distance to M-31. Hale Observatories photograph copyright© by the California Institute of Technology and Carnegie Institution of Washington, D.C.

Caption for pages 68-69.

Discovered in 1659 by the Dutch astronomer Christian Huygens, the Orion nebula is a massive cloud of interstellar dust and gas 25 light-years in diameter. Over 1,400 light-years away, it merely appears as a hazy star to the unaided eye, but when viewed through a large telescope and recorded by modern highly sensitive photographic emulsions, the delicate, wispy nature of the nebula (believed to be a star creche) is captured. Kitt Peak National Observatory photograph copyright© by the Association of Universities for Research in Astronomy, Inc.



the 19th century was almost exclusively what is now called astrometry and celestial mechanics. The chief occupation of astronomers was either mapping the positions of objects in the sky or calculating their orbits and motions. Astronomers also searched for new objects — planets, satellites, asteroids and comets.

Comets were particularly profitable discoveries — at least in the U. S. and Canada — because H.H. Warner, a comet-lover from Rochester, N.Y., offered a prize of $200 for each one sighted. A sharp eyed young photographer from Tennessee, Edward Emerson Barnard, bagged the prize so many times that he used the proceeds to pay for his house!

Astronomy was, in short, the province of a unique breed of extraordinarily patient and keen-eyed observers. Nightly, by the sputtering light of a dripping and smoky oil lamp, they mapped features on planets, measured the separation and position angle of innumerable double stars, or estimated the shift of lines in the spectrum of a star to determine its velocity with respect to Earth, using only two instruments in all three activities: a telescope and their eyes.

The advent of photography about 1840 did not immediately revolutionize the visual activities of observers. For decades, the available photographic processes were far too slow, insensitive and temperamental to permit much that was useful beyond rank experimentation. When photography became practicable on a daily basis, it opened unexplored vistas that had hitherto been completely inaccessible.

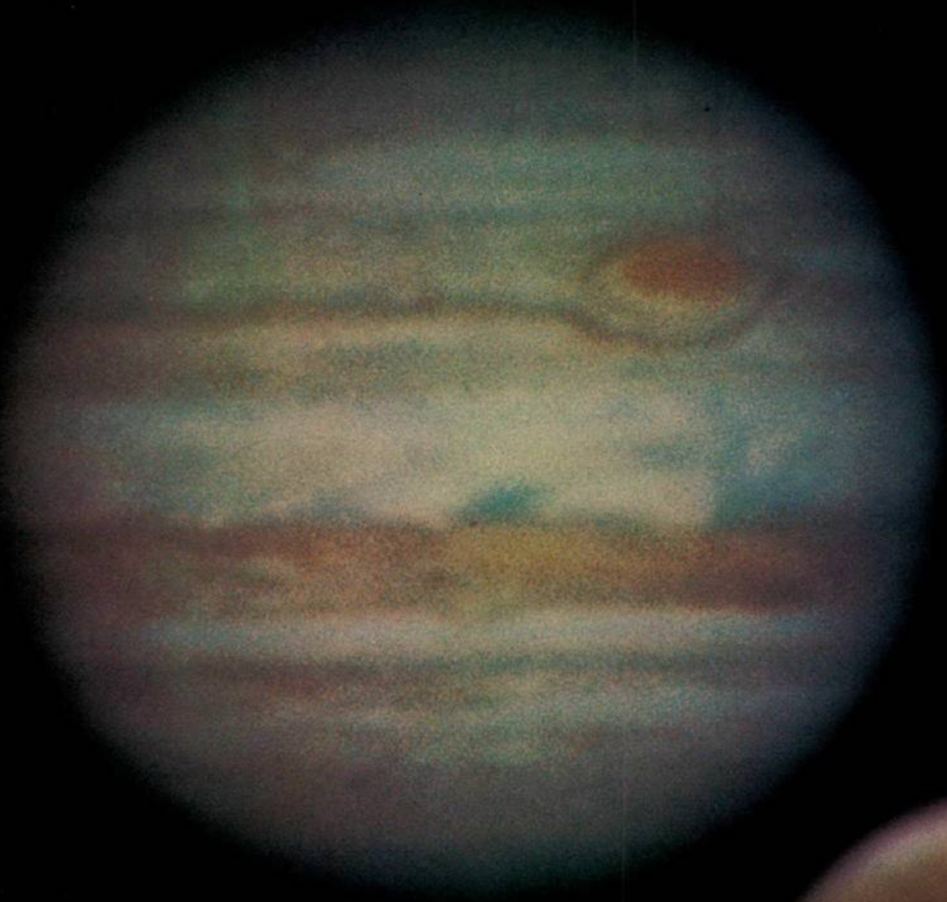
The history of photography is a classic case of a number of people independently and simultaneously solving a problem whose time had come.

It had been known as early as 1727 that silver nitrate was sensitive to light; a number of 18th century experimenters attempted unsuccessfully to capture images on sensitized paper. The main problem plaguing these efforts, however, was how to fix the image so that it was permanent and would not continue to darken with each subsequent exposure to light.

By the 1830s, two Englishmen, William Henry Fox Talbot and John Herschel (son of Sir William Herschel), independently devised a similar process of "photogenic drawing". Talbot originated the concept of first making a paper negative from which many positive pictures could be produced, although Herschel coined the terms "negative" and "positive".

Talbot fixed his pictures with a solution of common table salt. Herschel, however, discovered that "hyposulphite of soda" was more effective, which explains why the fixer — although a somewhat different chemical (sodium thiosulphate) in today's darkrooms — is still called "hypo".

At the same time, Louis Jacques Mande Da-



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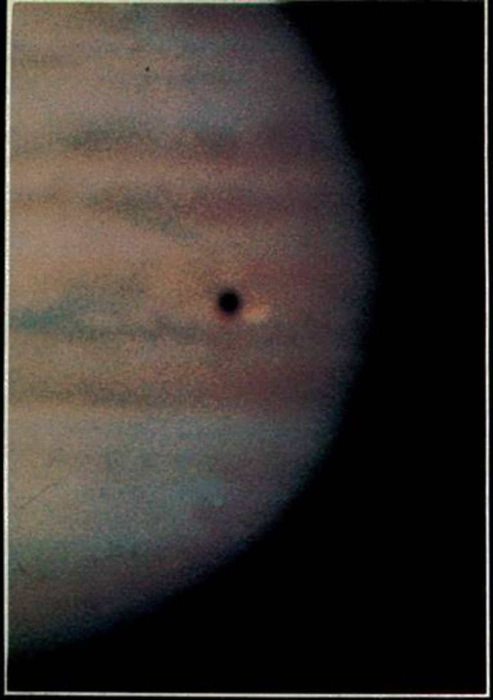

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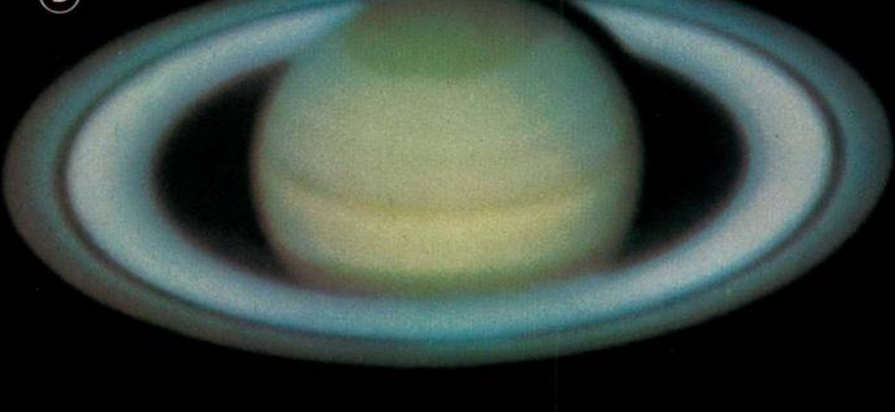

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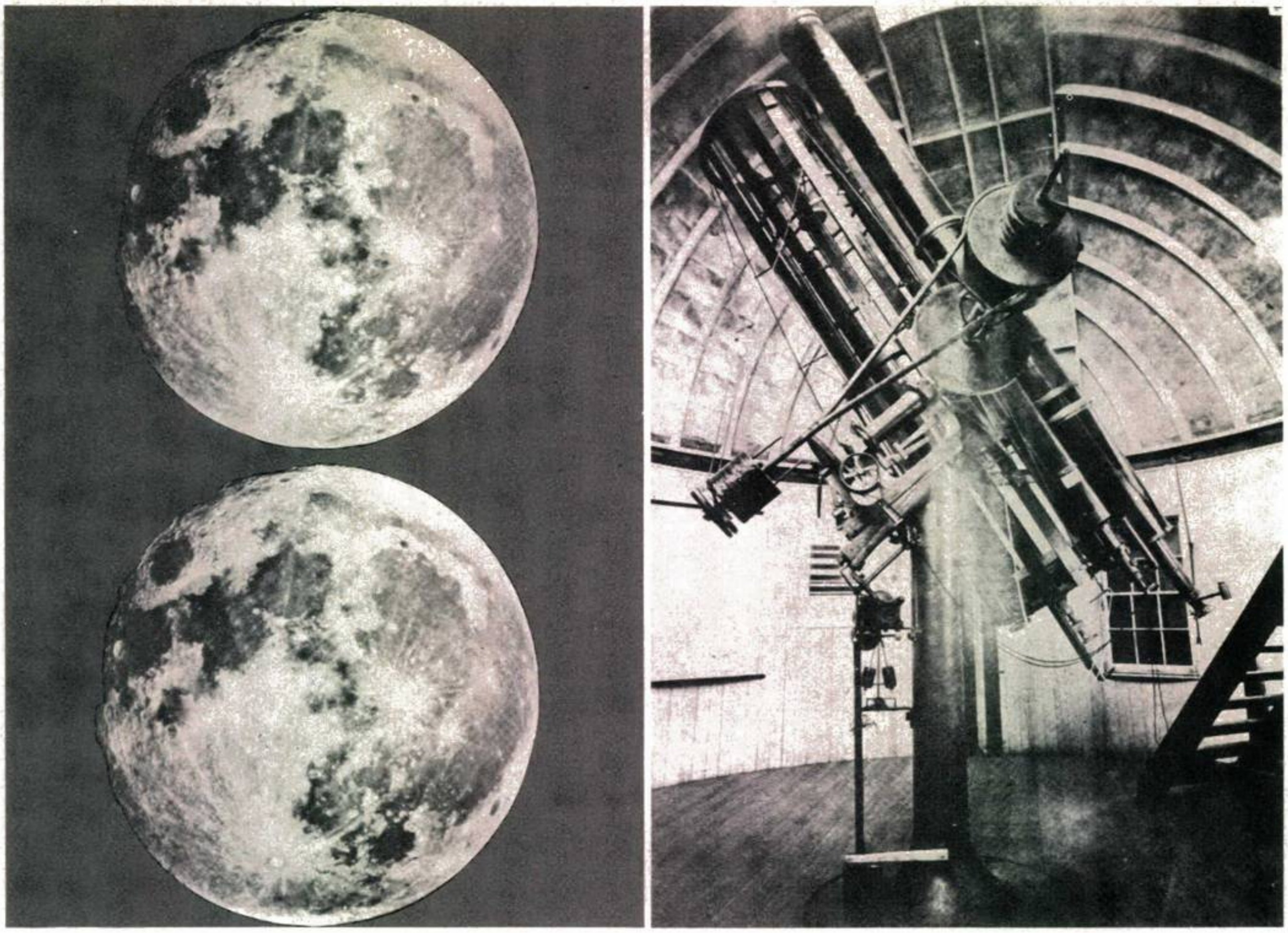


Opposite: Great strides in planetary astrophotography have been made since the 19th century. These photographs, taken within the last decade, are among the best planetary exposures obtained by surface based astronomical instruments. The detail displayed in the Jupiter photographs (A and B) is excellent. The colorful dark belts and lighter zones constantly vary in hue and size as the turbulent Jovian atmosphere shifts. B shows the shadow of Io, closest of the Galilean satellites, cast on Jupiter's cloud cover as the satellite transits the planet. The photograph of Mars (C) was taken during its 1969 opposition. The dark surface feature, Syrtis Major, is prominent at the center of the Martian disk. The filmy appearance of the eastern (left) limb is due to evening haze on the planet. A composite of 16 images, D is possibly the best photograph taken thus far of Saturn. Obtained in March 1974 with a 61 inch telescope stopped down to 40 inches, excellent detail can be seen in the planet's ring system. Lunar and Planetary Laboratory photographs. Above left: These stereoscopic photographs of the moon were taken by John Whipple on Feb. 7 and April 6, 1860. Harvard College Observatory photograph. Whipple used Henry Draper's 28 inch reflector (above right) to obtain the stereoscopic lunar photos. Photograph courtesy of John William Draper Memorial Park.

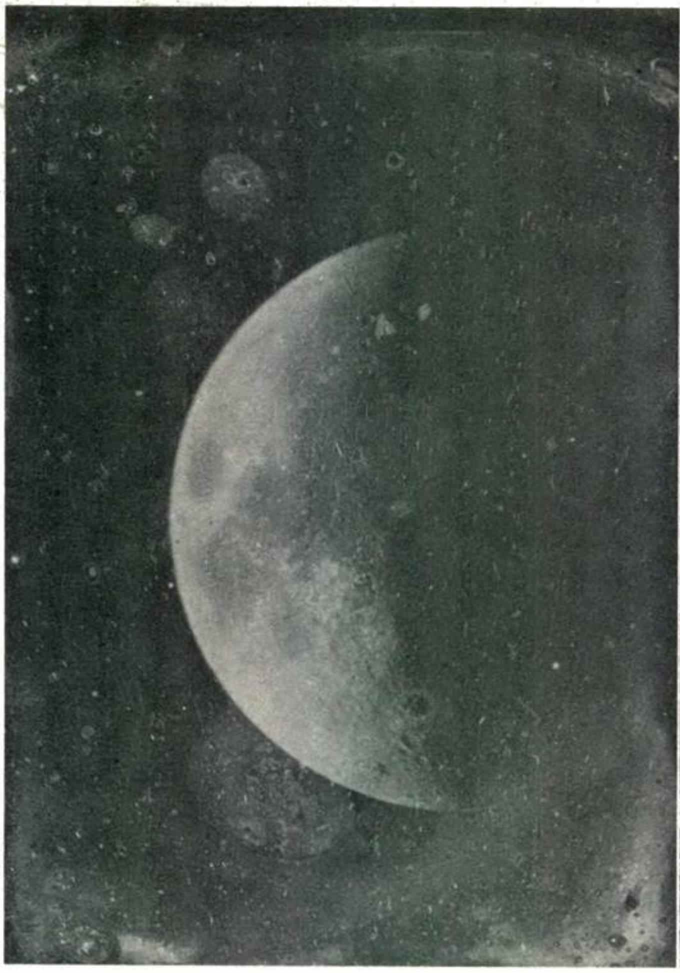
guerre — a French illusionist painter, physicist and inventor — was working on a process different from photogenic drawing which he labeled daguerrotype.

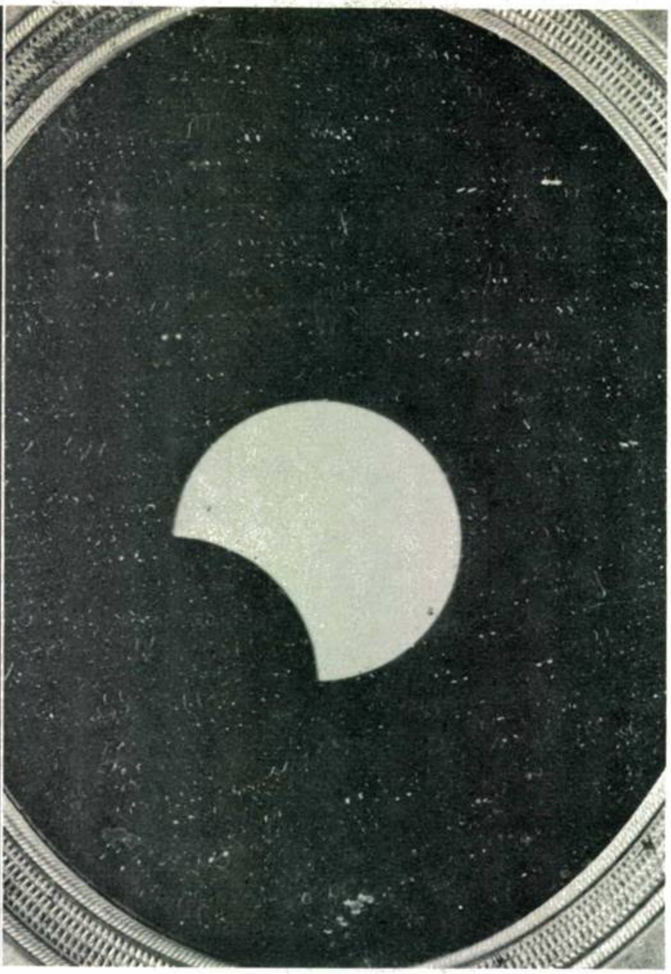
Daguerrotype was potentially a rather lethal method of getting a picture. A sheet of copper was plated with silver and put into a closed box where it was exposed to the vapor of iodine crystals. The iodine and silver combined to form silver iodide, creating a golden yellow surface. At that point the plate was sensitive to light.

The plate was put into a dark slide and set into the body of a camera obscura (the predecessor of today's cameras), which had been previously focused on a subject. The cover of the dark slide was withdrawn and the lens uncapped for the exposure, which generally extended through a significant portion of an hour even in bright sunlight. (That may account for the tired, grim expressions on the faces of people in those old pictures.)

After the exposure, the plate was inserted into another closed box where it was treated with the fumes of heated mercury. Good ventilation was, obviously, mandatory in the darkroom. As the mercury vapor settled onto the portions of the plate that had been chemically affected by the light, the image appeared. The excess silver iodide was removed by rinsing the plate with hypo. The plate was then dried and mounted under glass.

Daguerre immediately recognized the scientific potential of his invention. He experimented with photographing spiders under a microscope, as well as unsuccessfully trying to get a picture of the moon. He was also the first of the independent experimenters to go public with his discovery, approaching the French astronomer-physicist Dominique Francois Arago in the late 1830s. By January 1839, Arago had reported Daguerre's invention to the French Academy of Sciences.





Above left: John Whipple took this daguerrotype of the moon, one of the early photographic recordings of the lunar body, on Feb. 26, 1852. Above right: The July 28, 1851 partial eclipse of the sun was also captured by Whipple. Harvard College Observatory photographs. Opposite: The central regions of the Milky Way were photographed by the early astrophotographer, E.E. Barnard. This long exposure was taken in 1905 from Mount Wilson. Yerkes Observatory photograph, University of Chicago.

The news quickly swept through the scientific community. Some people, including Talbot, scrambled to get their own investigations into print so that they would not lose their priority. Others dropped their own half-successful investigations to discover the true potential of daguerrotype.

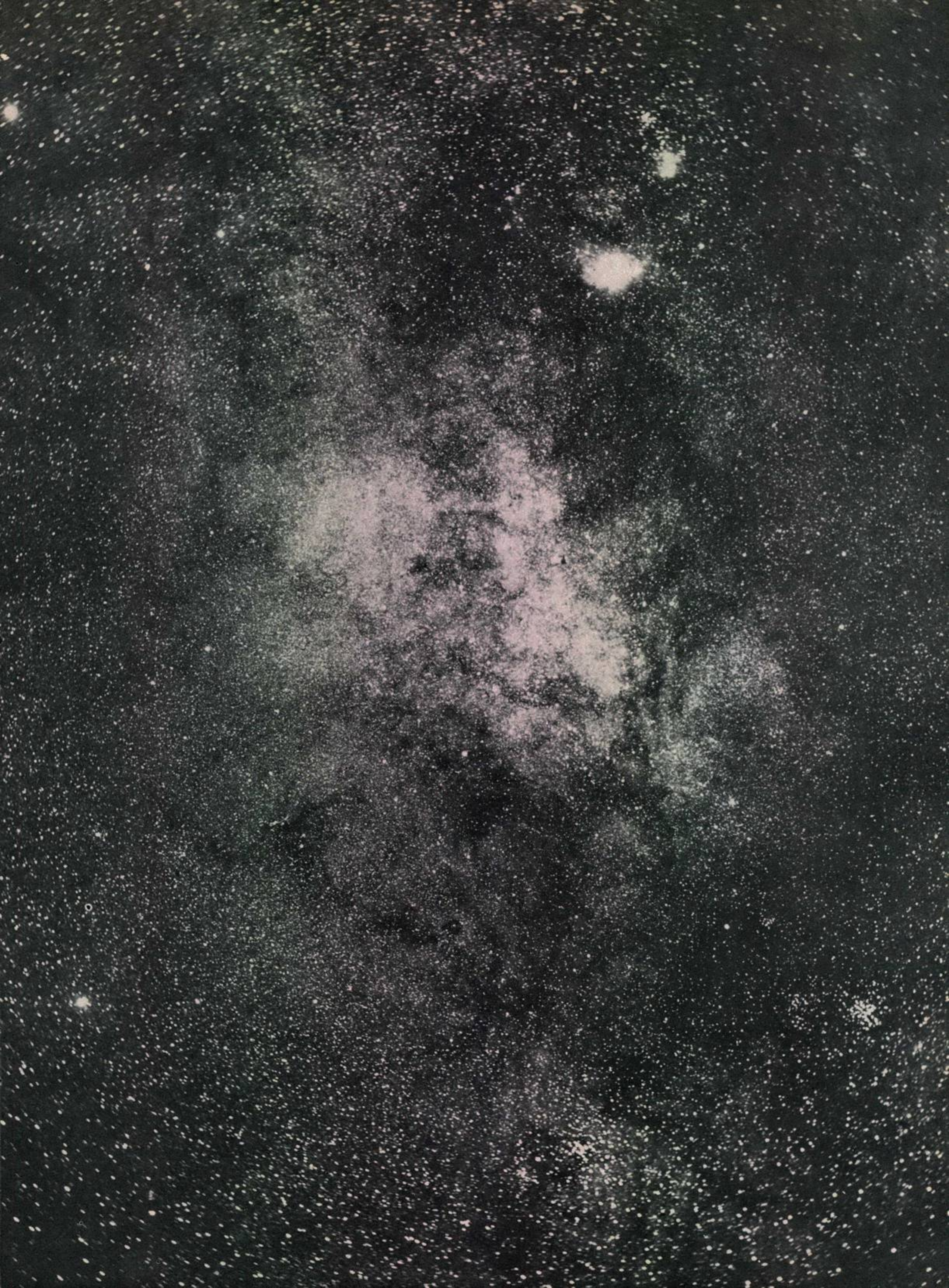
One of the latter was American astronomer John William Draper of New York University. Draper had been studying the action of moonlight, flames and colored lights on paper prepared with solutions of bromine. His main problem had been the common one of fixing the images.

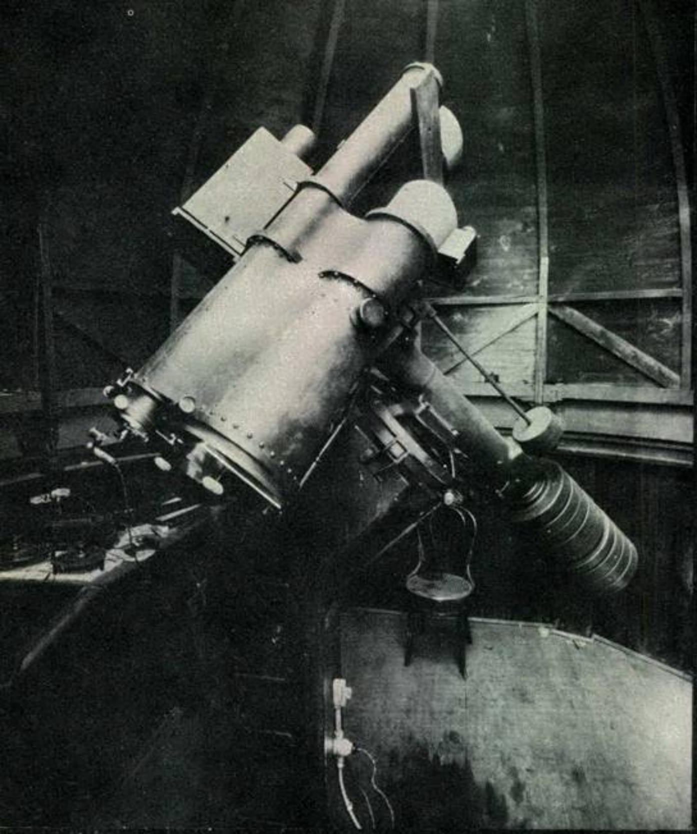
When he turned his attention to the daguerrotype process, however, he so improved the method by March 1840, that he obtained a daguerrotype of his sister, Dorothy Katherine Draper. That picture, the first photograph of a human being, was as much due to the fact that Draper figured out how to flood the subject with sunlight without roasting her, as it was to his accelerating the speed of the process. When he later attempted to photograph the moon with one of his supersensitized plates, he actually succeeded in overexposing the plate on his first try.

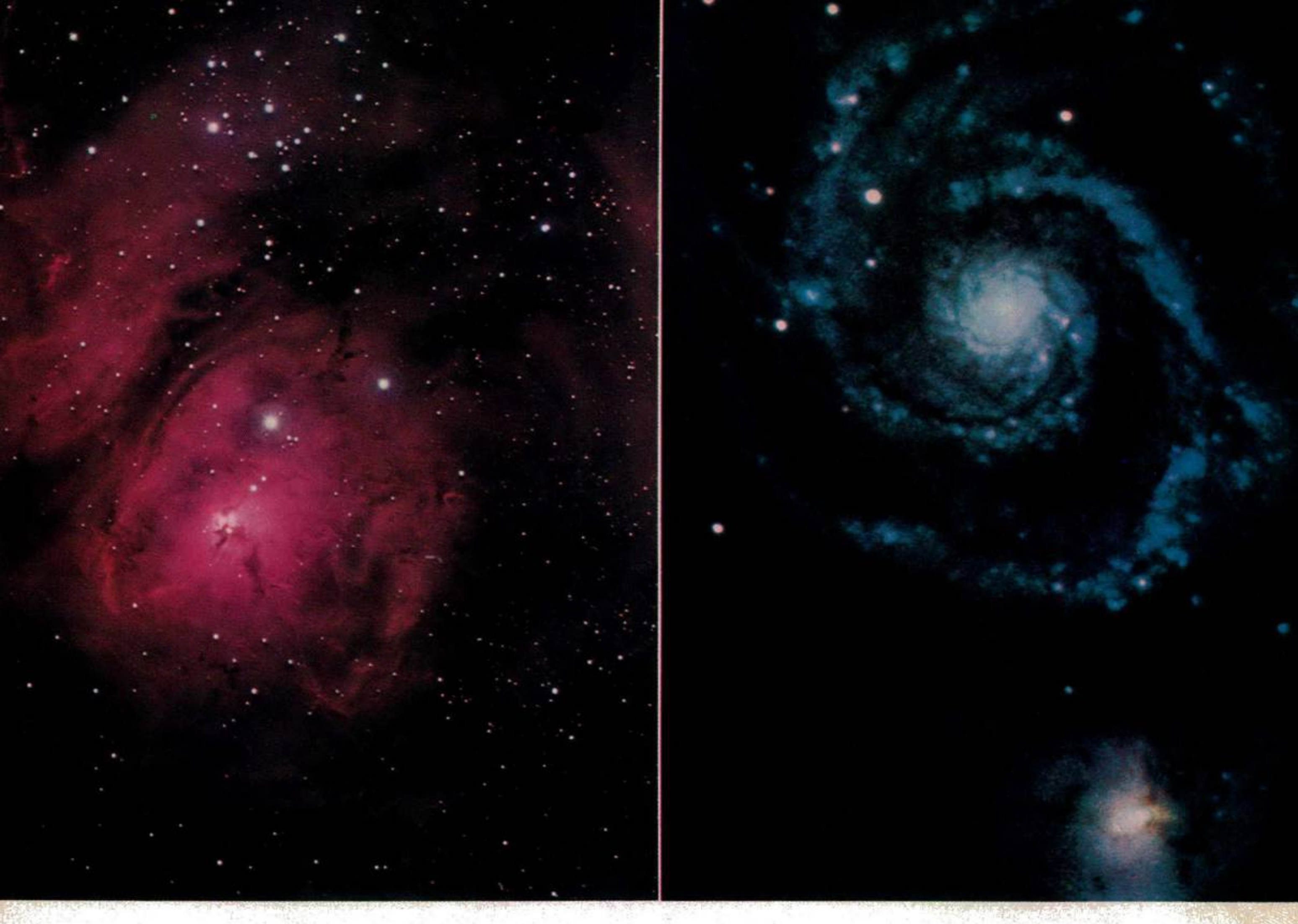
That first lunar photograph nevertheless required a half hour to record an image of the moon one inch in diameter, and improvement over the original sensitivity of the daguerrotype. Within the next decade, advances made the daguerrotype sensitive enough so that the exposure needed to photograph the moon had been increased to several seconds.

The Harvard people began getting heavily into photography. William Cranch Bond, director of the Harvard College Observatory — which boasted a new 15 inch Merz and Mahler refractor, one of the two largest in the world at the time — enlisted the aid of John Adams Whipple, the ace Boston daguerrotypist. Whipple wasn't just a good chemist blessed with mechanical ingenuity; he was also determined to make *beautiful* pictures — not simply serviceable ones.

On the night of July 16-17, 1850, Whipple took the first daguerrotype of a star — Vega. The photograph required an exposure of 100 seconds. The following December he made a plate of the moon that three months later won him a gold medal at the Crystal Palace Exposition in London. Another fine photograph of the moon by American astronomer







Opposite, top left: Barnard's triple photographic telescope allowed him to take three pictures simultaneously at different image scales. In this view, several smaller cameras are attached, providing still more pictures. Top, right: When this photograph was taken in 1905, astronomers were undecided concerning the existence of obscuring matter in space. This and other similar pictures were powerful evidence that "dark nebulae" did exist. Bottom: The cluster of luminous "nebulae" in Virgo also posed a mystery to astronomers: They did not understand the nature or distance of these objects. We now know this is a cluster of galaxies located almost 70 million light-years from us. Yerkes Observatory photographs, University of Chicago. Above: Modern color photographs of deep sky objects have an impact undreamed of by Barnard. At left is the Lagoon nebula in Sagittarius. Kitt Peak National Observatory photograph, copyright© by the Association of Universities for Research in Astronomy, Inc. At right is the spiral galaxy M-51 in Canes Venatici. United States Naval Observatory photograph.

George P. Bond (son of William Cranch Bond) was also a sensation at the 1851 London exposition.

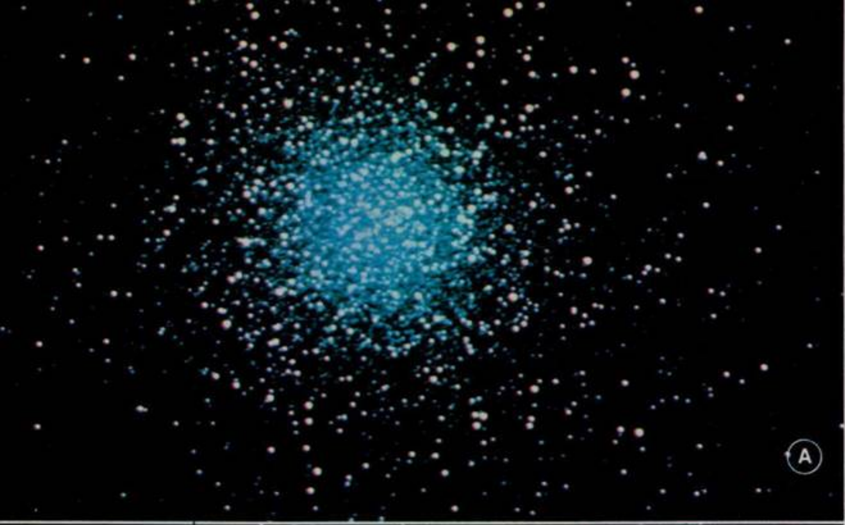
Attending the London Exposition was Warren de la Rue, a well-to-do English astronomer and inventor who had made his fortune manufacturing paper. Impressed with Whipple's lunar photograph, De la Rue returned home to experiment with making such pictures for himself. Instead of using the daguerrotype process, however, he employed the wet-plate collodion process, newly invented by Frederick Scott Archer.

The advent of the collodion process actually marked the second of the three phases of early photography (the daguerrotype marking the first). Collodion was a colorless, semiviscous fluid produced by dissolving guncotton in a mixture of alcohol and ether. The fluid was spread upon glass where it formed a transparent membrane. When impregnated with silver salts, it was rendered susceptible to the action of light.

The principal advantage of the collodion process was that it was much faster than daguerrotype. Its principal disadvantages, however, were that each plate had to be made just before use, had to remain wet during the entire exposure, and had to be developed immediately afterward.

After preliminary success in taking collodion pictures of the moon with a 13 inch reflector, De la Rue built an observatory in 1857 specifically dedicated to celestial photography. He did not like "flat" pictures of celestial objects, however, and sought to represent the sun and moon as the solid objects they are. He did this by taking stereoscopic photographs of these subjects.

De la Rue found, by trial and error, that if he took one picture of the sun, waited 26 minutes and then took another, the rotation of the sun provided the means for obtaining the stereoscopic effect he wished. One stereoscopic view he made in 1861 showed the sunspots as definite depressions in the solar surface with the bright faculae being much higher in the photosphere. In one of his pictures,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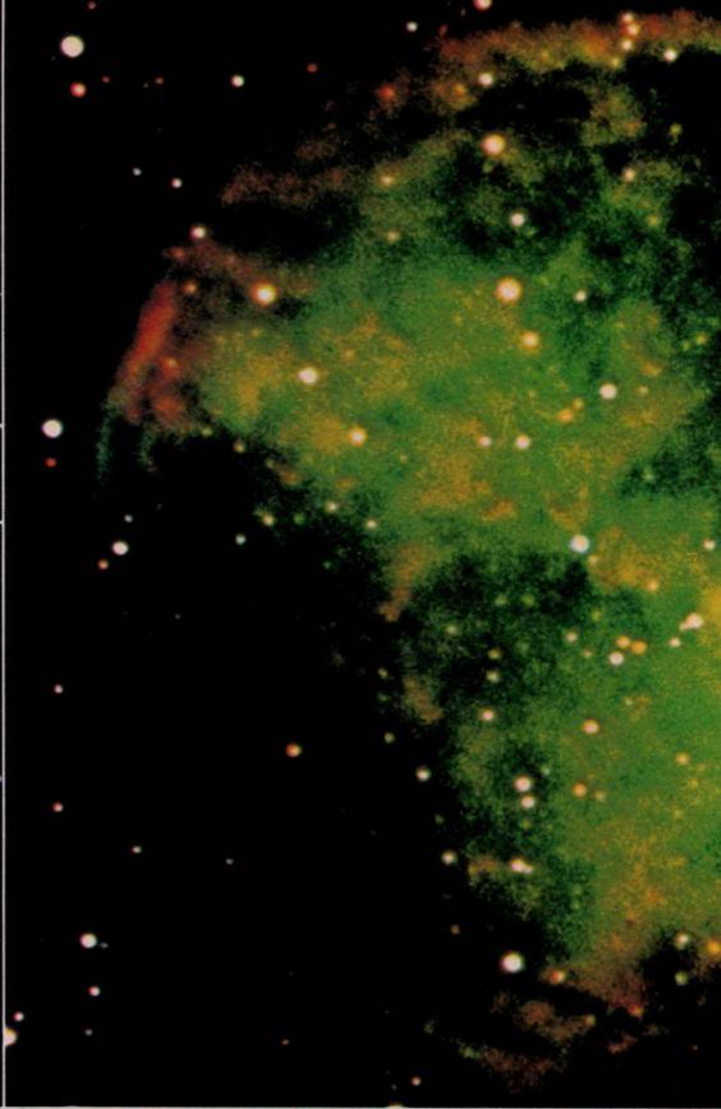

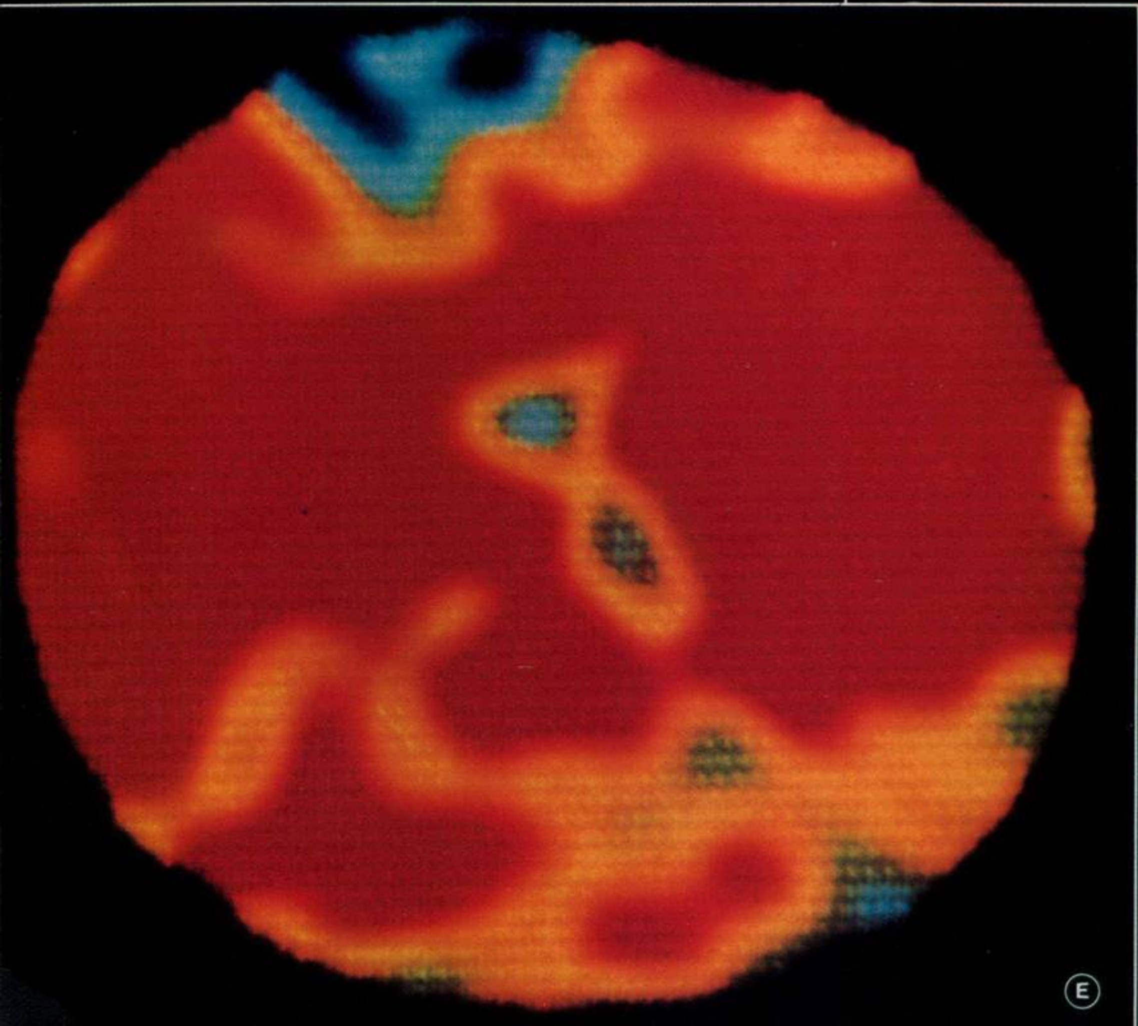
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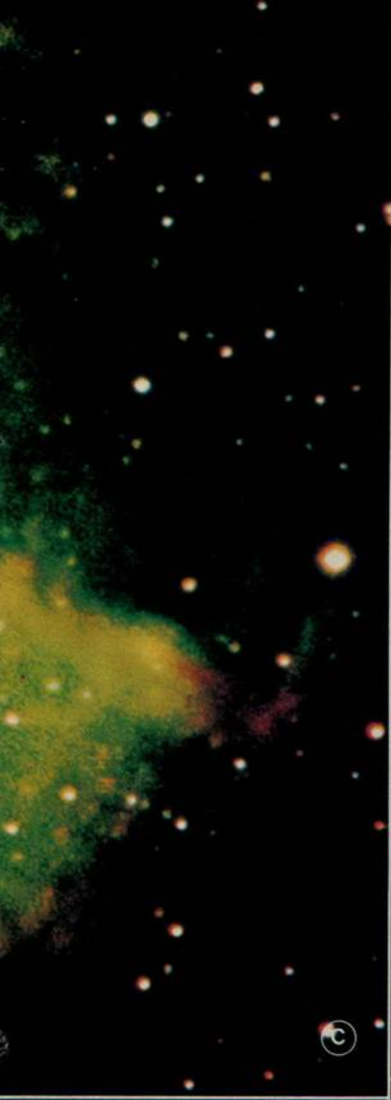
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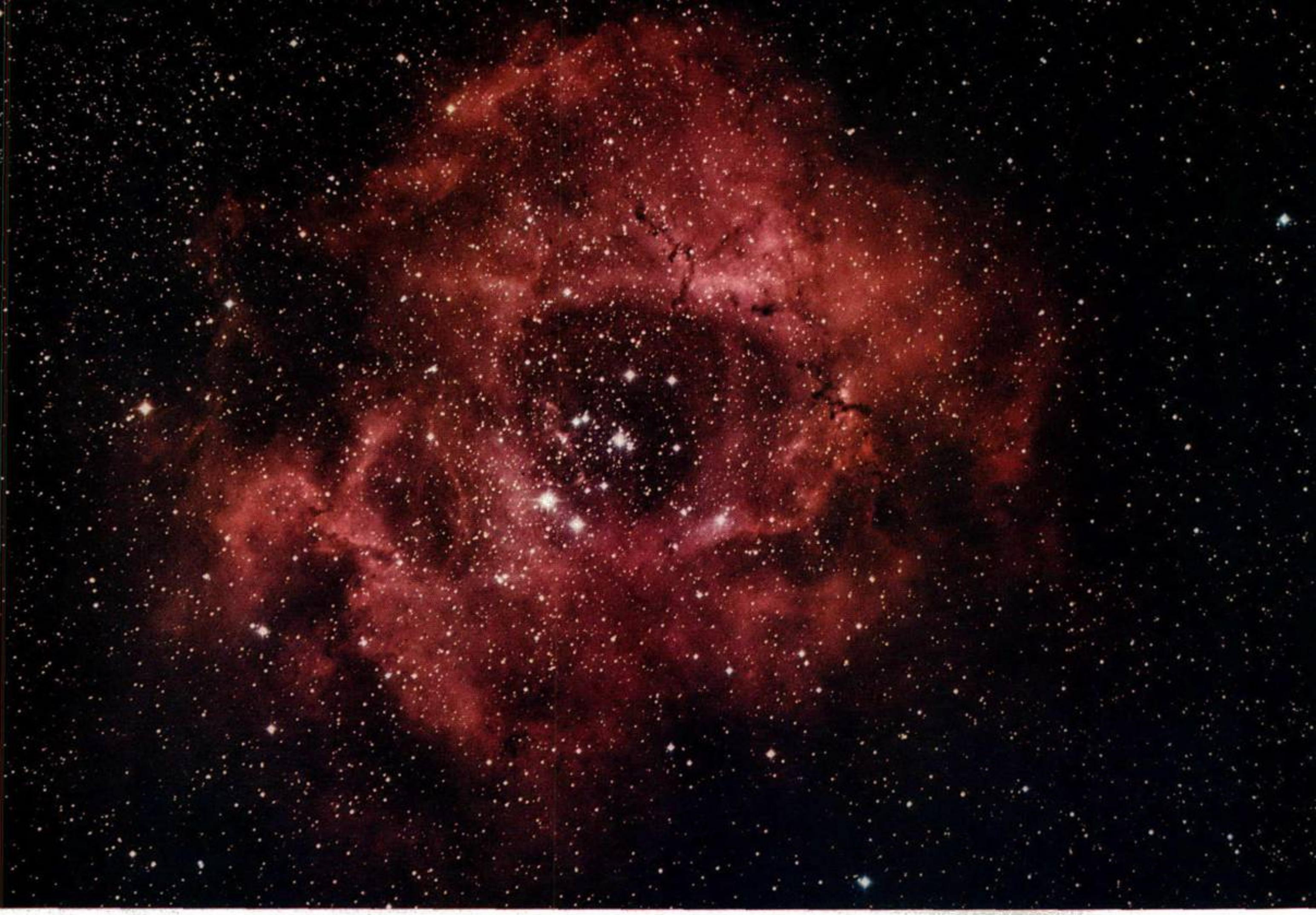


Astrophotography has come a long way since the daguerrotypes of the 1840s. Modern developments in processing systems and image intensifiers have allowed astronomers to photograph the surface of another star, Betelgeuse (E). The globular cluster M-13 (A) — better known as the Hercules cluster — is 20,000 light-years away. The Eagle nebula (B), the Bubble nebula (G) and the Rosette nebula (this page, above) are large clouds of interstellar gas and dust that are nurseries for newborn stars. The two most prominent planetary nebulae in the sky are the Dumbbell nebula (C) and the Ring nebula (H). The Pleiades cluster (D) consists of several hundred young stars whose brightest components are doomed to short lifetimes. The Crab nebula (F) marks the location of a supernova that was seen by oriental observers over 900 years ago. M-82 (I) is an unusual galaxy undergoing huge explosions. D, F and above: Hale Observatories photographs copyright© by California Institute of Technology and Carnegie Institution of Washington, D.C. B, E and H: Kitt Peak National Observatory photographs copyright© by the Association of Universities for Research in Astronomy, Inc. C and I: Lick Observatory photographs. A and G: U.S. Naval Observatory photographs.

De la Rue could even see parts of the faculae sailing at a considerable height over a spot.

Solar photography helped solve some of the long-standing debates about the sun, specifically concerning the nature of the "red protuberances" or prominences that had been observed during total solar eclipses. Some astronomers thought the prominences were a phenomenon of the sun; others argued that they were phenomena in the moon's atmosphere. A sequence of photos De la Rue took during the total solar eclipse of July 18, 1860 clearly showed that the moon successively advanced *over* the prominence just before totality, proving beyond question that the prominences belonged to the sun.

The problems connected with the use of the collodion process prevented many observatories from adopting photography into their observing programs. In 1871, Richard L. Maddox changed all that with the introduction of a gelatine substitute for collodion that incorporated silver bromide as the light sensitive substance. Maddox's plates were to be used dry, and could be prepared at leisure, exposed nearly indefinitely and developed when convenient. Moreover, his dry gelatine plates were five times more sensitive than the wet collodion plates.

The dry plates opened the third phase of astronomical photography, ushering in the era of useful, convenient photographic observations.

Maddox's discovery led to the feasibility of making spectroscopic studies. In 1876, Sir William Huggins turned his own telescope on Vega and obtained its spectrum. Five years later he captured the spectrum of Tebbutt's comet and discovered that some of the comet's light was emitted by the fluorescence of carbon compounds, and some was merely reflected sunlight.

The following year, Huggins and Lady Huggins gleaned the spectra of the Great Nebula in Orion. They concluded that its tenuous glowing matter was in a high state of either thermal or electrical excitement, and determined that it was probably physically associated with the stars embedded in it. Furthermore, the spectrum of the Orion nebula was not the same as the spectrum of the Great Nebula in Andromeda — a discovery which later revealed that "spiral nebulae" such as the Andromeda were actually galaxies like our own Milky Way.

At the Harvard College Observatory, astronomers began a program of systematically classifying stars according to their spectra. By night, male observers obtained photographic plates as fast as possible; by day a team of 17 female computers carefully examined the spectra and sorted out the stars by type — a classification that ultimately led to the Hertzsprung-Russell diagram and subsequent knowledge of how stars are born, evolve and die.

A by-product of that work was the discovery of a completely new class of double stars — spectroscopic binaries. These are stars so close together that they orbit their common center of gravity in hours or days; they may even be in physical contact with each other. Too close to be resolved as two stars even in the largest telescope, the lines in their spectra are doubled, indicating that the light is being emitted by two sources.

Star fields were photographed six months apart when Earth was on opposite sides of its orbit by Charles Pritchard of Oxford, and others. Painstaking hours were spent examining the photographic plates to determine whether any of the nearer stars had minutely shifted their positions as a result of parallax. In this way, astronomers photographically determined the distance to more than 100 stars.

With such a powerful tool as photography at hand, it was a natural step for observers to lust for a complete photographic survey of the heavens. Friedrich W.A. Argelander at Bonn took a photographic census of the brighter stars in the northern sky and published his **Bonner Durchmusterung** in 1863. Benjamin Apthorp Gould, founder of the **Astronomical Journal**, went to Cordoba, Argentina and extended Argelander's work to include the southern sky; the result was the companion work, **Cordoba Durchmusterung**. Between the two catalogs some 458,000 stars were recorded, which one contemporary writer called the "roll-call of the stellar army". The same writer declared: "Stars not entered in it have no official existence; should they fade and vanish the fact cannot be attested; should they brighten into conspicuousness we are obliged to regard them as 'new' for lack of previous acquaintanceship." Both catalogs are still used today.

For some, a half million stars was not comprehensive enough. In April 1887, the International Astrophotographic Congress, hoping to produce a master photographic chart, met in Paris to catalog no less than 20 million stars! Eighteen observatories — none of them American — were each assigned the construction of a 13 inch photographic refractor with a focal length of 11.25 feet. Participating astronomers were to use these identical telescopes to make a series of one hour exposures on plates encompassing six square degrees. The total number of plates required by the project was 14,000. The task of reducing the number of observations proved so herculean that even by 1938, the project had not been completed.

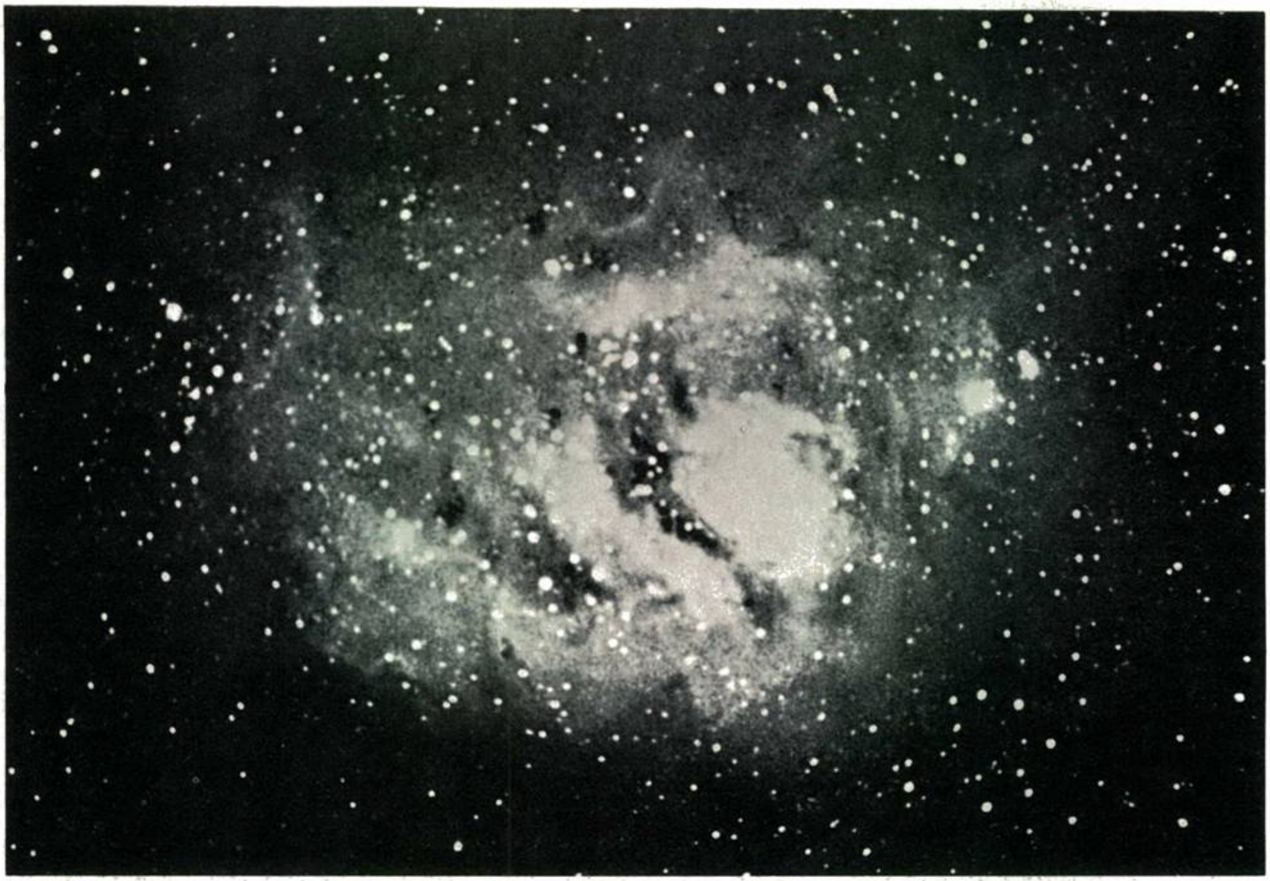
Meanwhile, comet seeker Barnard began to systematically photograph the Milky Way from Lick Observatory with a contraption that can scarcely be dignified by the word "telescope". It was a portrait lens six inches in diameter with a focal length of 31 inches, strapped to a sturdy equatorial mount inside a tiny 10 foot dome. With that makeshift instrument, Barnard recorded the intricacies of the Milky Way, discovering over 200 tiny globules of dark gas that are still known as Barnard objects. These globules, not much larger than our solar system, are now believed to be clouds that eventually contract and give birth to young stars.

Until the late 19th century, the photographic films available to astronomers were still too slow to photograph the planets in a time brief enough so that the image would not be washed out by Earth's turbulent atmosphere. By the beginning of the 20th century, however, photography had clearly established itself as an integral and necessary part of astronomy.

Photography provided a way of recording for all time the appearance of an object at a particular time. In general, the photographic process recorded more data per unit time than the naked eye, and recorded it more accurately. The photographic plate built up the image over the entire time of a long exposure, thus capturing much fainter objects than the naked eye could. And last, when different emulsions became available, photographic films could perceive objects at wavelengths totally inaccessible to the naked eye.

One major stumbling block in the way of telescopic photography was overcome in 1932 by Bernard Schmidt. Astronomers were held to photographing small fields with large telescopes because distortion became a limiting factor if attempts were made to enlarge the field of view. Schmidt introduced a method which used a correcting lens, enabling astrophotographers to take previously unforseeable sky survey photographs spanning a field 6.5 degrees across.

In many ways photography became the "glue" that bonded astronomy and physics into the powerful "new astronomy" of astrophysics — a discipline that revealed new analogies between celestial and terrestrial phenomenon. The **Sidereal Messenger** of 1888 prophetically announced that "there is no longer a 'new' and an 'old' astronomy. The two are fused into one, to the enormous advantage of both. It seems hardly possible to be over-sanguine as to the results." ◆



M8 with the QUESTAR 3½

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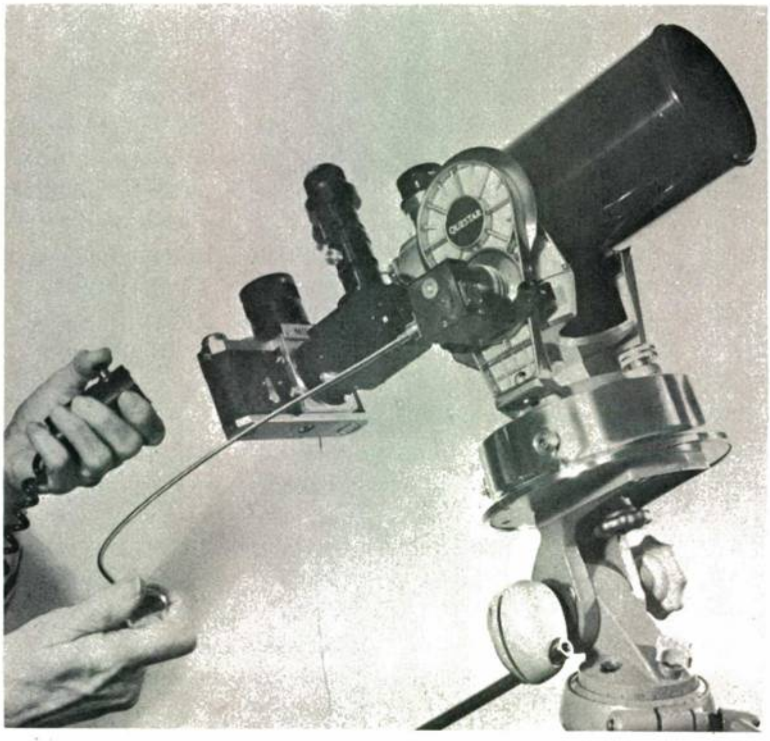
M8 was taken at Table Mountain in central Washington. It is a one hour twenty-five minute exposure at F12.2. Mr. Entrop says the air was very rough. Below is the Starguide mounted on the Duplex Questar.



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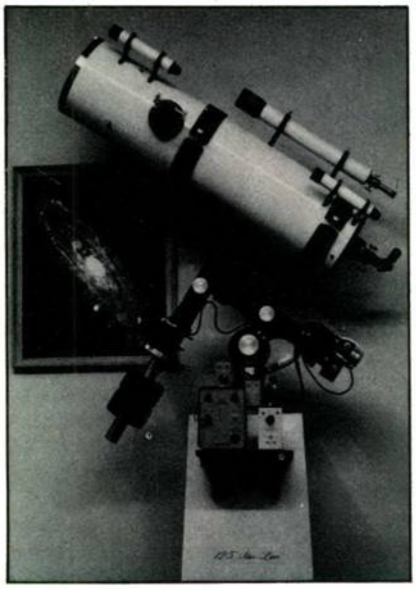

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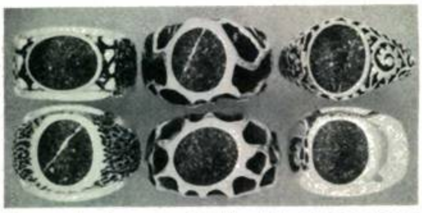

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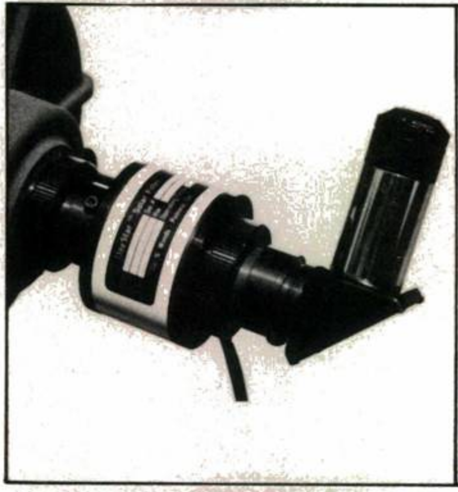

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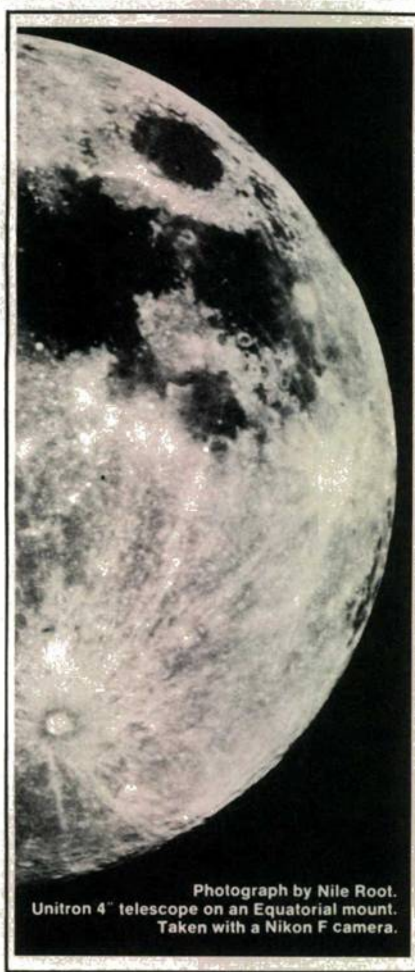

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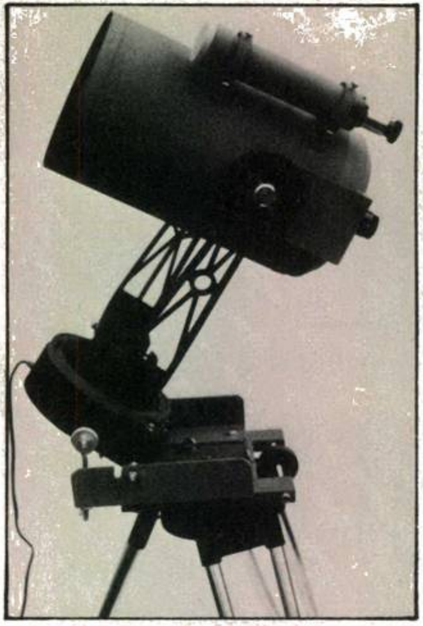

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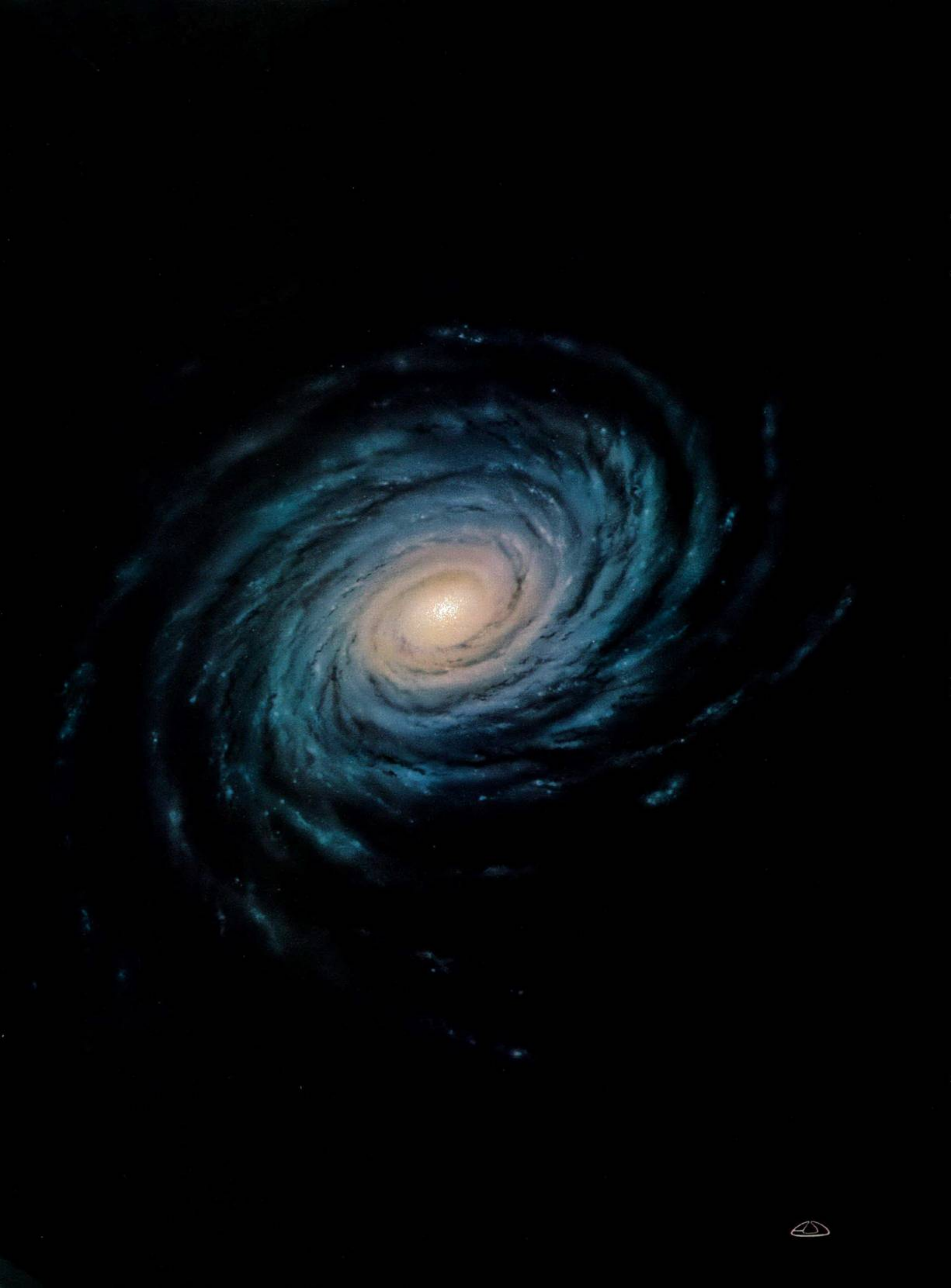


THE UNIVERSE UNFOLDS: 1900–1950

At the end of the 19th century, the same problem which had fired the enthusiasm of John Winthrop in 1761 and David Rittenhouse in 1769 — that of the average distance from Earth to the sun — was still an unsettled question. In 1900, however, a close approach of the asteroid Eros to Earth allowed more precise measurements.

Simon Newcomb, addressing the American Astronomical Society, called for active, worldwide participation to obtain a precise determination of the asteroid's position. Applying Kepler's laws of planetary motion to this information would better establish the size of Earth's orbit. American participation in this effort was substantial; all results were sent to A.R. Hinks in England for analysis. Hinks had the assistance of a young postgraduate student from Princeton who provided invaluable aid; the result was the creation of data reduction techniques which Hinks used to determine, in 1910, the average solar distance of 92.83 million miles. His young assistant was Henry Norris Russell, a man destined to be a dominant force in American astronomy for almost half a century.

Born in 1877 in Oyster Bay, N.Y., Russell was a student of Charles A. Young, and admirably continued his mentor's life work — the spectroscopic examination of the sun and stars, and the interpretation of these observations in the light of modern physical theory. Russell's first major study was to determine, by photographic means, the distances to stars by measuring their annual parallaxes. Once the distance to a star is known, its actual brightness — or intrinsic luminosity — can be determined. This physical quantity is a measure of how much energy is released by the star.

While Russell was in the process of evaluating his photographic parallax plates, he began a long correspondence with Edward Charles Pickering of Harvard, where the vast spectral classification project was now going full steam. Pickering suggested that Russell compare his luminosities to the spectra of the stars being studied; this was done using Harvard resources. Almost at once, Russell found — to his amazement — that among stars with red spectra, two very distinct types of stars existed: small, feeble stars and great luminous ones. But only bright ones existed among the blue stars. It soon became apparent that a very definite relationship existed for all stars when their spectra were compared to their luminosities. While a correlation like this was new to Russell, it had been anticipated by others, including Dutch astronomer Ejnar Hertzsprung in 1911. Russell, however, placed the relationship (now known as the Hertzsprung-Russell, or H-R, diagram) on firm observational footing.

Astronomers were now faced with having to explain how the two types of red stars could have grossly different luminosities. The answer resided in the very nature of the stars themselves. But so little was known at that time about the structure and generation of energy within a star that the answer was not apparent. The luminosity difference could be due to a difference in mass or size. More information was obviously needed about the physical characteristics of *individual* stars. Curiously, this

It was not until after the turn of the century that astronomers became certain the sun is located in a spiral galaxy, such as the one depicted on the opposite page. But new findings on objects located both in and outside the Milky Way galaxy made such a conclusion inevitable. This painting shows the Milky Way as it might be seen from a distance of several thousand light-years, and is an example of some of the finest astronomical art produced today. Artwork by Adolf Schaller.

As recently as 1920, the exact nature of "spiral nebulae" was imperfectly understood. An object such as that pictured here — NGC-7331 in Pegasus — was variously explained as (for example) a condensation in the Milky Way, or as a new solar system in formation. It was only in 1924 that Edwin Hubble, utilizing discoveries made by Henrietta Leavitt and Harlow Shapley, became convinced that these objects were actually separate galaxies in themselves, millions of light-years away. As instruments became more sophisticated, photographs could become more detailed, culminating in the views obtainable through the 200 inch telescope at Mount Palomar. Hale Observatories photograph.

type of information comes only from the study of double stars.

There is a specific class of double stars where the two stars, in orbit around a common center of gravity, pass in front of one another as seen in our line of sight. A careful analysis of the variable amount of light coming from the stars as they eclipse one another was shown by Russell to yield the sought-after star dimensions.

In 1910, Russell turned to these "eclipsing binaries" (with the help of his student, Harlow Shapley) for the answer. Shapley industriously examined 87 double star systems at Mount Wilson under the watchful eye of Hale and the supervision of Russell.

The analysis of eclipsing binary systems yielded the fascinating results that some of the brighter red stars were of extremely low density, making them tens and sometimes hundreds of times larger than the sun! These were truly giant stars when compared to their fainter red counterparts.

The relationship between luminosity and spectral class, made graphically clear by the H-R diagram, is in essence a correlation between the intrinsic brightnesses and surface temperatures of the stars. The nature of the correlation suggested that the prevailing theory of stellar evolution was incomplete. Instead of aging through a linear cooling and contracting process, beginning life as a blue star and ending it as a red one, Russell believed that his newly found red giants were the youngsters. They contracted and heated until they became blue hot; only then did they begin to cool upon further contraction. Russell's theory was a revival of one suggested by Sir Norman Lockyer in 1890, but Russell's treatment was a masterful fitting of solid data. Its only drawback was the poor understanding of the behavior of matter under extreme conditions found in stellar interiors. While Russell's theory was never fully accepted, the diagram he created became the observational proving ground against which all subsequent theories have been tested.

The problem of stellar evolution was soon attacked by scores of theoretical and observational astronomers. In England, Arthur Eddington, James Hopwood Jeans and John Milne endlessly debated the behavior of matter inside stars, and how energy might be transferred from within the star throughout

its atmosphere. Everyone wondered what the unknown source of energy was that made the sun and stars glow. While no generally accepted theories appeared for some time, one major contribution, suggested in part by Russell, was that the structure of a star, and its position on the H-R diagram, was determined by its mass and chemical composition.

The energy source problem was partially solved in the late 1930s by Hans Bethe and George Gamow. They found that the fusion of hydrogen to helium could account for the prodigious amount of energy released by the sun. Notable contributions from American astronomers in the 1950s finally yielded the present-day, generally acceptable theory of stellar evolution. Today, stars are "seen" to be born, live their lives and die in the flash of a nova on hundreds of high speed electronic computers found at many universities and observatories in America and around the world. No one has ever seen a star go through its life cycle in reality. Our computers are the only places where billions of years of life can be contracted into a few moments.

The story of the development of the theory of stellar evolution, especially in the United States, is incomplete without studying the larger context of the problem — the structure and form of the entire sidereal system. The history of how the Milky Way galaxy was discovered is one of the proudest aspects of American science.

Since the days of Lord Rosse's visual discovery of those nebulous spiral star systems, the question of the nature and role of these nebulae was widely controversial. Some suggested these nebulae were rotating objects within the Milky Way, condensing to form stars and planets. This notion matched the prevalent 19th century theory of the origin of the solar system. In the Nebular Hypothesis of Laplace, the planets were believed to have formed by an ejection process in the contracting solar nebula. As deep sky photography developed, faint "knots" seen in the spiral arms were believed to be planets in formation.

By 1899, a completely revised form of the Nebular Hypothesis was formulated by two University of Chicago scientists — Thomas C. Chamberlin, a geologist, and Forest Ray Moulton, an astronomer. They believed the spiral nebula was an integral step in the formation of a solar system. However, the idea of condensation under gravitational attraction was, in 1900, the only generally accepted source of energy for the sun and stars. Its incorporation into the Nebular Hypothesis was inadequate to account for the distribution of angular momentum in the solar system.

The Chamberlin-Moulton theory, therefore, had to abandon the Nebular Hypothesis and the question of star formation. There were others, however, who felt that nebulae were not within the Milky Way, but were "island universes" at inconceivably vast distances from us. The controversy over the nature of the spiral nebulae was a fundamental question that dealt with the very structure of the observable universe. Was our Milky Way the entire visible universe, or was it merely an island in a hierarchy of stellar systems?

For over 250 years, the band of light that represented the Milky Way to Earthbound observers suggested that we lived in a disk shaped universe. By 1900, irregularities in the brightness of various portions of the Milky Way, demonstrated by Edward Emerson Barnard's deep sky photographs, suggested to some that we might be within a spiral, perhaps one similar to the many photographed by James Keeler at Lick Observatory. Several early models of the Milky Way's structure placed the sun near the center.

Definite progress toward better understanding of the Milky Way's structure was made between 1916 and 1920 when Harlow Shapley began to exploit a recently discovered, remarkable class of variable stars called Cepheids. Studied extensively by Henrietta Leavitt at the Harvard College Observatory, Cepheids were found to be numerous in the two Magellanic Clouds. Leavitt found that periods of brightness variation seemed to be correlated with the stars' average visual brightness — the brighter

continued on page 95

Expanding Universe

Man has attempted to describe the structure of the universe he lives in since the dawn of history. Believing the cosmos could be understood, he has pursued the study of the physical makeup of the universe — cosmology — through religious, metaphysical and scientific means. Once a discipline that treated the character of the universe as an orderly system of nature, conforming to certain ultimate principles, cosmology now relies on the interpretation of astronomical data gathered by optical and radio telescopes and the accompanying host of auxiliary apparatus.

Primitive cultures had only two instruments at their disposal for studying the universe: their eyes and their imaginations. Their interpretations of the universe were limited by day-to-day experiences; they saw a universe in terms of the daily events and objects around them.

Five thousand years ago, the Babylonians believed that Earth occupied the central portion of the universe. It was divided into two seven-tiered pyramids: Living beings occupied the upper part, while the dead resided in the lower section. Surrounding Earth was an ocean of water, which supported the curved solid vault of the heavens. The heavenly vault was subdivided into eight shells: Each of the seven known "planets" (the moon, the sun, Mercury, Venus, Mars, Jupiter and Saturn) occupied one of the subshells, while the outermost layer was reserved for the fixed stars.

Ancient Egyptians believed the universe was a large, nearly rectangular box with a mountain-ringed Earth forming the bottom of the box. The sky, supported by four large tree trunks, stretched overhead like an iron ceiling. Some descriptions suggested it was flat, while others said it was like a vault. The sun, moon and stars were "lamps" hanging from strong cables. Under Earth was a counter-Earth: a mirror image of Earth and its heavens, peopled by the dead.

The Greeks, building on the Babylonian and Egyptian cosmologies, improved on them only to the extent that they removed the artificial supports. The established view, based on the thoughts of Thales of Miletus and Ptolemy of Alexandria, placed Earth as the immobile center of the universe, with the other heavenly bodies describing complicated combinations of uniform circular motions. There were other views, of course: Philolaus believed Earth was a sphere that revolved around a "central fire" (though not the sun), while Aristarchus of Samos and Heracleides Ponticus suggested that Earth revolved around the sun. The acceptance of these ideas was hampered by the widespread belief in the perfection of heavenly bodies, held by Pythagoras and Plato.

Buddhists were not troubled by thoughts of the surrounding universe. The structure of the natural world was not essential to Buddhism. Believing the universe was without beginning or end, their essential concern was human conduct, not the courses of heavenly objects.

The Chinese, however, produced some remarkably modern cosmological concepts as early as the first century A.D. One school of thought, the Hsüan Yeh, said that the heavens were empty and void of substance. "The sun, the moon and the company of stars float freely in the empty space, moving or standing still. All are condensed vapor." A European writer, Matteo Ricci, noted several "absurdities" in Chinese cosmology when he wrote in the 16th century: "They say that there is only one sky and not 10 skies; that it is empty and not solid. The stars are supposed to move in the void, instead of being attached to the firmament....Where we say there is air between the spheres, they affirm there is a void."

While the Chinese were refining their cosmological models, European cosmology languished. No advances were made on Greek conceptions of the universe until 1543, when Polish astronomer Nicolaus Copernicus published his theory that Earth revolves around the sun. Subsequent discoveries of the motions of the bodies of the solar system by Kepler, Galileo's mechanics, and the hypothesis of universal gravitation by Newton set the stage for advances in cosmological thought.

The concept of Newtonian gravitation was extended beyond the solar system by Sir William Herschel early in the 19th century. While studying the motions of binary star systems, Herschel found that the sun moved relative to the vast aggregation of stars known as the Milky Way. Although the idea that stars might be arranged in "island universe" systems was suggested in the mid-18th century by Immanuel Kant, Jean Lambert and Thomas Wright (whose remarkable theory on the Milky Way's structure was all but ignored), Herschel's findings were the first to lend any observational support to the concept. Herschel's son, Sir John, later confirmed his father's conclusion that the Milky Way represented the "fundamental plane of the stellar system" and that it could not last forever. The sun was cast from the center of man's universe, and the lofty self-image that man was the center of creation went with it.

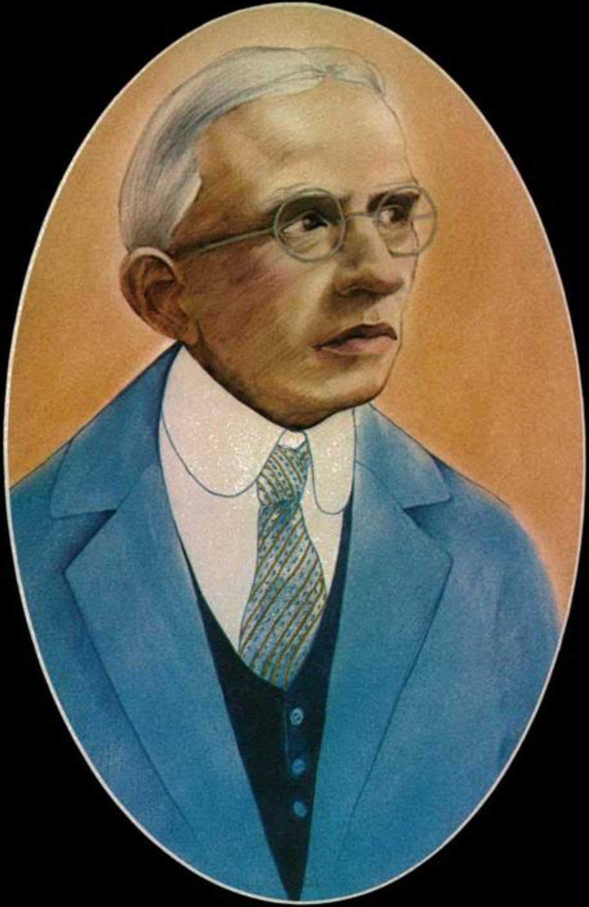
The questions of the composition and distribution of nebulae occupied astronomers for most of the 19th century. Although many astronomers believed the Milky Way comprised the entire universe, others said the issue couldn't be resolved until the nature of nebulae was better understood. Some nebulae were found to display spiral structures; they were not generally believed to be beyond the Milky Way, but "small eddies in the convolution of the great one".

Improvements in the measurement of the proper motions of spiral nebulae finally placed them outside the Milky Way, although many astronomers — including Harlow Shapley — initially found it difficult to accept this finding.

By 1914, American astronomer Vesto Slipher found that a number of objects beyond the Milky Way were moving away from it at speeds of several hundred miles per second. Subsequent research included W. de Sitter's findings that Einstein's General Theory of Relativity indicated the most remote celestial objects would be moving away from us at speeds approaching that of light. Finally, it was definitively demonstrated that all galaxies (except members of the Local Group, which included M-31) were fleeing from us. In 1929, Edwin Hubble showed that the observed velocities of recession increased in proportion to the distance between objects. Observations by Milton Humason and others supported Hubble's contention, extending it to greater and greater distances.

Fundamental questions raised by the work of Hubble and others have evoked new problems. Because galaxies and the recently discovered quasars act as though the universe were expanding like a balloon, is there a limit — both in speed and distance — to the expansion? Why is it expanding at all? Did the expansion result from a single "big bang", or are there cycles of big bangs and contractions that repeat over and over again? Or is the steady state theory, advanced by Fred Hoyle, Thomas Gold and Hermann Bondi — which represents the universe as being in a "stable, self-perpetuating state" — the answer?

Although the quest for knowledge has taken man far from the primitive conceptions he once held of the universe — from the view of Earth as the center of the universe to an insignificant component of one of an untold number of stellar systems, "an archipelago of island galaxies stretching away behind one another" — the solutions are not yet at hand. These answers, if we ever have them, belong to the future.

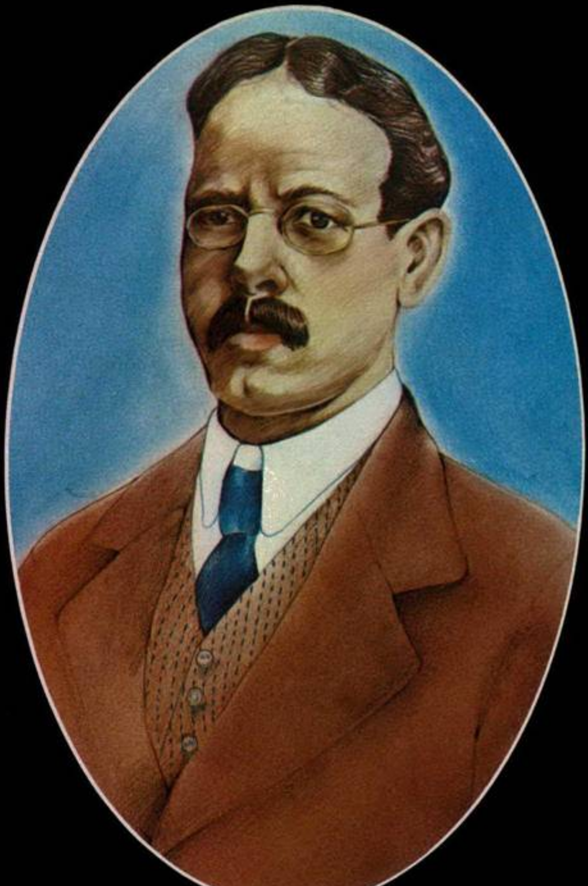


Henry Norris Russell (1877-1957)

Henry Norris Russell was probably the most famous and revered American astronomer of the first three decades of the 20th century. Although he is remembered primarily for the Hertzsprung-Russell diagram (a synthesis of Russell's observations and the earlier, similar work of the Danish astronomer Ejnar Hertzsprung), Russell made a number of other valuable contributions to astronomy and astrophysics.

Working at Princeton Observatory, he announced in 1908 that Saturn's rings could be no more than 13 miles thick — a dramatically drastic reduction of earlier estimates. Russell developed (with Harlow Shapley) a theory that answered many questions about variations in the light of eclipsing binaries. He showed that the planets in the solar system could not have formed from the nearby passage of a star. In the mid-1930s, Russell suggested that stars possessing 10 times the mass of Jupiter might represent "missing links" between planets and normal, self-luminous stars.

Russell was possibly the only early American investigator of stellar structure and evolution. While some of his early theories were confirmed, his own interpretation of the Hertzsprung-Russell diagram and his theories of stellar evolution — though they adequately explained the observational facts known in 1913 — were subsequently contradicted by later investigation.

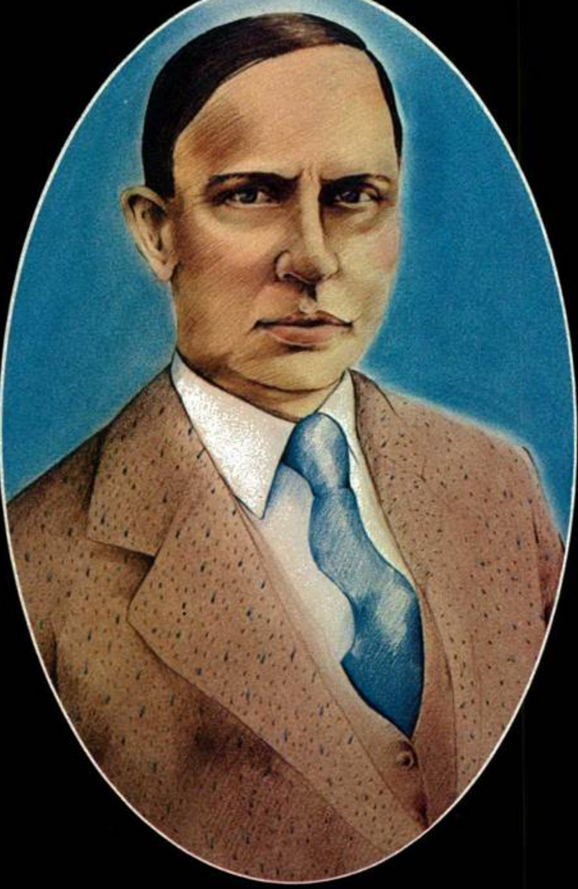


George Ellery Hale (1868-1938)

"Bigger and better telescopes" could well be an epitaph for the life of George Ellery Hale, the "guiding light" behind three of our nation's most prominent observatories. Born in Chicago, Hale graduated from the Massachusetts Institute of Technology in 1890, and immediately plunged into an incredibly wide range of activities. By 1900, he had organized his first observatory (Kenwood Observatory in Chicago); done research in Berlin; joined the faculty of the University of Chicago as an associate professor (later professor) of astrophysics; invented and developed the spectroheliograph; established the prestigious *Astrophysical Journal*, and organized Yerkes Observatory, building the 40 inch refractor with the firm of Alvan Clark & Sons.

If Hale slowed down after the turn of the century, it was only because he was involved in larger projects. In 1904, he began organizing the Mount Wilson Observatory (of which he was director until 1923), and built the 60 and 100 inch reflectors there. He undertook an even larger task in 1928, when he organized Mount Palomar Observatory. The 200 inch reflector, although not completed until 12 years after Hale's death, was his final attempt at telescopic perfection.

Hale's yearning for the "perfect" telescope is reflected in the last sentence of his book, *Signals From the Stars*: "Can one doubt that a telescope powerful enough to carry all these studies far beyond our present possibilities will prove profitable, not merely to the astronomer but to the physicist, the chemist, and to all who utilize the results of science in the many-sided problems of modern life?"

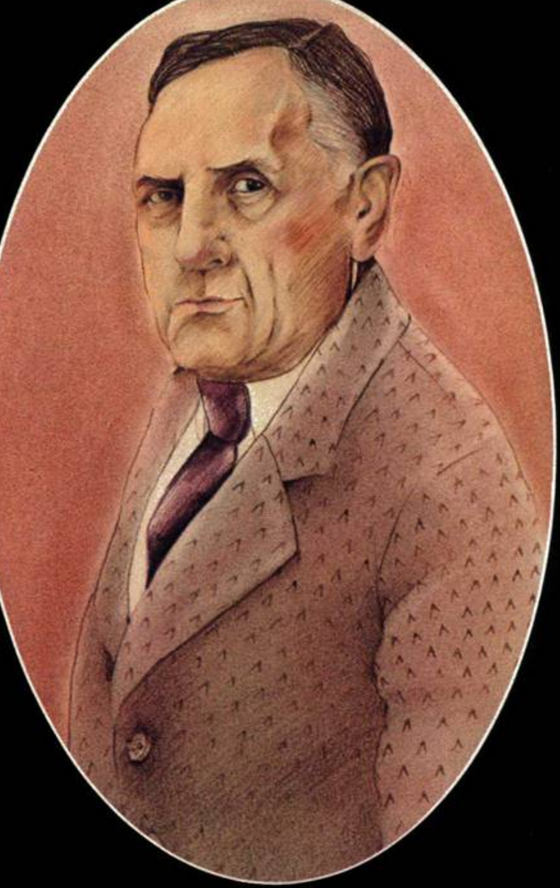


Harlow Shapley (1885-1972)

Harlow Shapley worked as a newspaper reporter in the early 1900s before entering Missouri University as a journalism student. Switching to astronomy, he received his bachelor's degree and went to Princeton to do graduate work on eclipsing binaries. While at Princeton, his ideas on deriving the distances of these binaries from their colors and spectra began to accrete. The subsequent publication of his 1913 thesis on eclipsing binaries brought him the attention of the world astronomical community.

After working at the 60 inch Mount Wilson reflector, where he conducted his study of Cepheid variables, Shapley left in 1921 to work as director of the Harvard College Observatory (HCO). Some scientists, including his former teacher Henry Russell, thought the move unwise. One of Shapley's colleagues, in a letter to a friend, said he didn't think "Shapley would be so foolish as to give up his astronomical career just to be director of that observatory."

Shapley did in effect give up his career in astronomy when he accepted the HCO directorship. He became, Charles Whitney said in his book *The Discovery of Our Galaxy*, "a public man: he administered his observatory; he worked to bring foreign scientists to America; he helped organize UNESCO. In short . . . he reached beyond science." Shapley also wrote a number of books for the popular press which combined astronomy, sociology and philosophy.



Edwin P. Hubble (1889-1953)

Edwin Hubble took a circuitous route to astronomy. Born in Missouri, his family moved to Illinois, where he was an outstanding athlete in high school and college. He took some astronomy courses while an undergraduate at the University of Chicago, and later studied law at Oxford. Although awarded a Rhodes scholarship during his last year there (1910), his letters home indicated a persistent interest in astronomy.

Returning to the United States to practice law in Louisville in 1913-14, Hubble re-enrolled in the University of Chicago and received a graduate degree in astronomy in 1916. George Hale offered him a job at Mount Wilson, but Hubble chose instead to enlist in the U.S. Army, fighting in Europe until Armistice Day. He joined the Mount Wilson staff in 1919, and remained there until his death in 1953.

Hubble believed the observable region of the universe was representative of the universe as a whole. In his book *The Realm of the Nebulae*, he mused on the task facing astronomers: "We know our immediate neighborhood rather intimately. With increasing distance, our knowledge fades, and fades rapidly. Eventually, we reach the dim boundary — the utmost limits of our telescopes. There, we measure shadows, and we search among ghostly errors of measurement for landmarks that are scarcely more substantial. The search will continue. Not until the empirical resources are exhausted, need we pass on to the dreamy realms of speculation."

continued from page 89

ones having the longer periods. Shapley seized upon the significance of this discovery. If the distance to one of these variables could be determined, then their *intrinsic* brightnesses could be related to their periods of light variation. Once this was done, Shapley would have an extremely powerful method for determining stellar distances. From an observation of a Cepheid's period, he could determine the star's actual brightness. Combining this with a measurement of its visual brightness, he could determine the distance to the star. The scheme's promise rested on the possibility that if the star happened to be in a cluster of stars, then the question of the distance to the cluster would also be answered.

Shapley first applied the Cepheid technique to determine the distance to globular clusters — those great spherical groups of stars that often contain Cepheid type variables. Shapley's goal was not the mere determination of distance to the globulars, but the true size of the Milky Way.

In 1916, at least 100 globular clusters were cataloged, but their exact relationship to the Milky Way was not clear. A year later, Shapley made an interesting observation: He noted that the globulars' distribution in space was symmetrical about the Milky Way's plane. They tended to center around a very bright portion of the Milky Way, located in the direction of the constellation Sagittarius. Shapley assumed these globulars were the "bony frame" of the Milky Way, with the center of their distribution locating the center of the Milky Way itself. His estimate for the sun's distance from the galactic center was large, thus making the Milky Way some 300,000 light-years in extent — approximately three times its presently accepted diameter. This great size made it difficult, if not impossible, to perceive of anything farther away, especially if the spiral nebulae seen were as large as the Milky Way. On this scale, the Andromeda nebula would have been 10 million light-years away. Shapley argued that this couldn't be, for novae observed in Andromeda indicated that it had to be much closer. Shapley assumed that novae there were similar to novae in the Milky Way. This "Principle of Uniformity", a trademark of Shapley's work, is applied today in virtually all theories of the universe.

Several lines of evidence developed in the years 1917 to 1920 that questioned Shapley's views. Vesto M. Slipher of the Lowell Observatory determined from spectroscopic studies that the spiral nebulae were in rapid rotation. If the nebulae were close, rotational components should be observed across our line of sight to the spiral nebula. If the nebulae were truly distant objects, then this proper motion would not be easily apparent. Adriaan Van Maanen of Mount Wilson, however, detected what he thought were actual proper motions of "knots" in the spiral arms of several large nebulae, apparently conclusive evidence that spiral nebulae were nearby and not island universes. The motions Van Maanen observed are now believed to be impossible to detect; his measurements remain an open question in astronomical history.

On April 26, 1920, astronomer Heber Curtis and Shapley engaged in the "great debate" over the nature of nebulae. Held before the National Academy of Sciences, this meeting took the form of a presentation of two beliefs on the size of the Milky Way, rather than an actual debate on the nature of spiral nebulae. The event was moot, since no solution to the problem was reached.

A young astronomer at Mount Wilson, Edwin Hubble, soon solved the question. Using Shapley's technique of distance determination via the period/luminosity relation of Cepheids, Hubble determined the distance to the Andromeda nebula. By taking multiple-hour exposures of the Andromeda spiral with the 100 inch telescope, he successfully resolved the nebula into an immense sea of extremely faint stars. "Among these stars," he said in his book **The Realm of the Nebulae**, "various types were recognized which were well known among the brighter stars in the galactic system. The intrinsic luminosities were known, accurately in some cases, approximately in others. Therefore, the apparent faintness of the stars in the nebulae indicated the distances of the nebulae. . . . The most reliable results were furnished by Cepheid variables."

Hubble found that the distance between the Andromeda nebula and the Milky Way was much greater than the size of the Milky Way. By 1924, he was convinced that spirals like Andromeda were separate galaxies every bit as large as our Milky Way. Another year passed before he formally announced his work, for Van Maanen was his direct superior at Wilson. By 1925, his work was common knowledge. The "Realm of the Nebulae" became the "Universe of Galaxies".

Four years later, Hubble announced an even more startling observation. Slipher and others had previously recorded very high velocities of the nebulae (now galaxies) as seen along the line of sight. Initially, it was believed that these motions were random and were partially due to the sun's motion around the center of the Milky Way. Hubble discovered these velocities correlated to the relative distances to the galaxies. He found that the fainter, more distant galaxies were moving away from us faster than the brighter, closer ones. A dedicated observer, Milton Humason spent countless hours in the following years at the Mount Wilson telescope recording spectra of galaxies that eventually confirmed Hubble's revolutionary concept of the structure and general expansion of the universe.

Hubble gave us two fundamental facts as a basis for the study of the universe. These two facts — that galaxies exist, and that they are all moving away from one another — remain the only two facts we can be sure of in the modern study of cosmology. ◆

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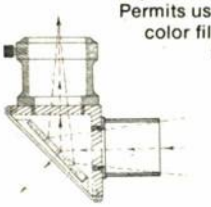

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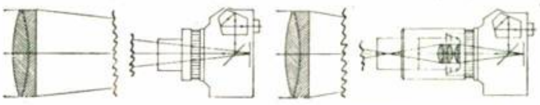

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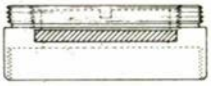

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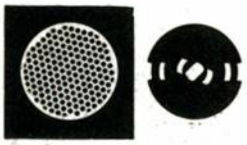

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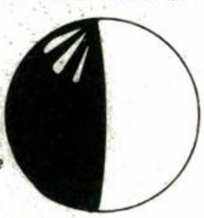

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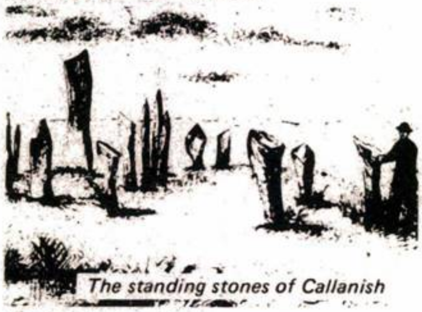

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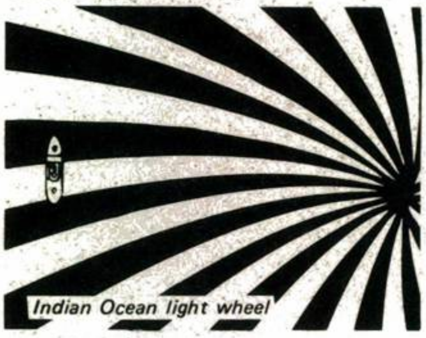

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Toward Man's Dream of Worlds Unseen: 1950-1976

When a young research physicist at the Bell Telephone Laboratories in New Jersey, Karl G. Jansky, began in the early 1930s to examine sources of atmospheric static at radio frequencies, he had no idea of the great discovery he was about to make: the detection of the "invisible universe" — the realm of radio astronomy.

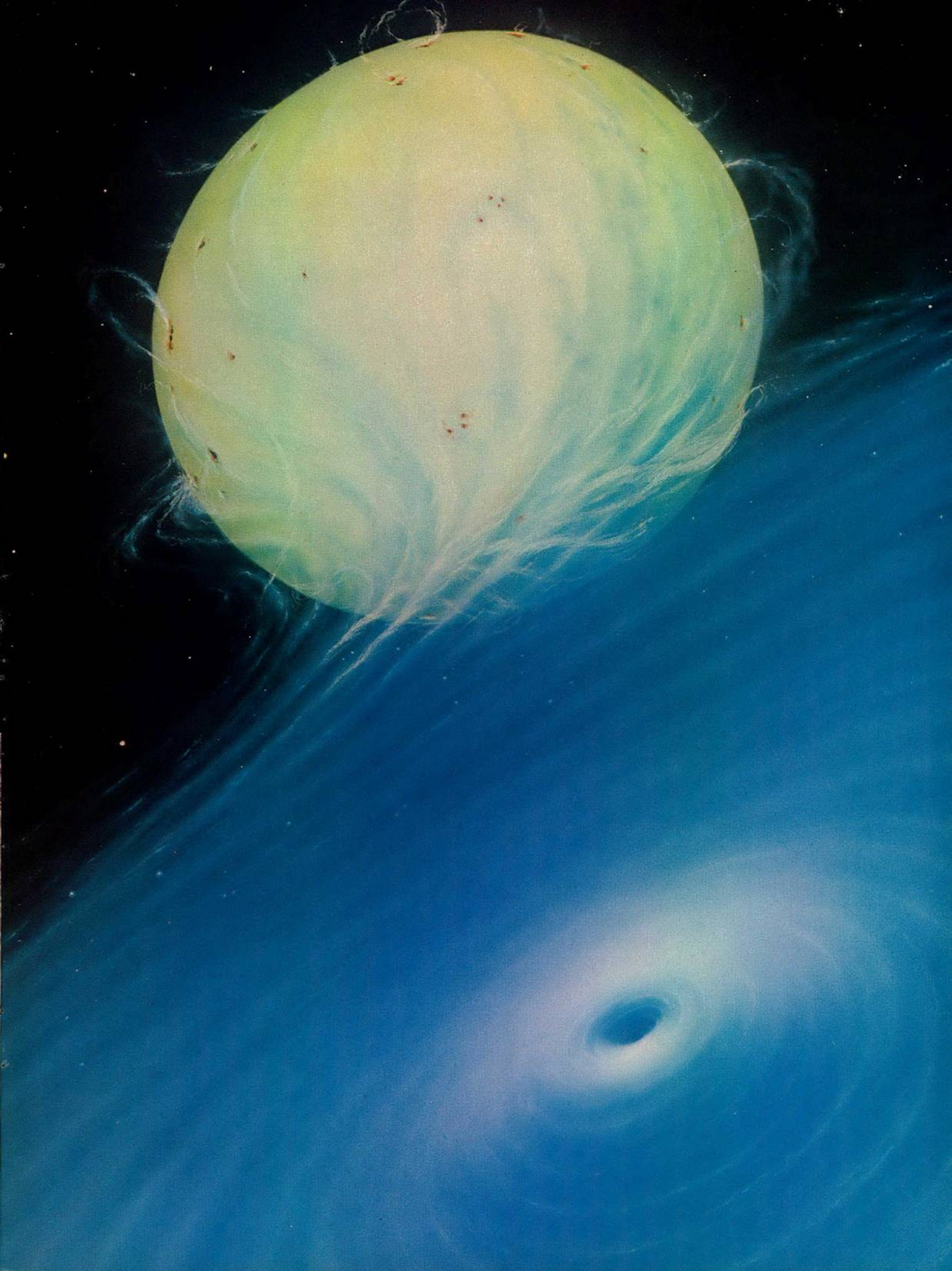
Jansky's assigned task was to determine sources of radio noise that interfered with long distance transmission. By 1932, he had identified three types of radio static: Two were due to local and distant thunderstorm activity, but the third, a steady hiss, was not generated by any terrestrial source. One important clue was the fact that the noise intensity seemed to be correlated with Earth's rotation. The source could not be fixed to Earth, allowing Jansky to reason that the source was extraterrestrial. The first suspect was the sun, but later observations showed the source drifted with the stars and not the sun. Its position was pinpointed after a year to be in the direction of Sagittarius,

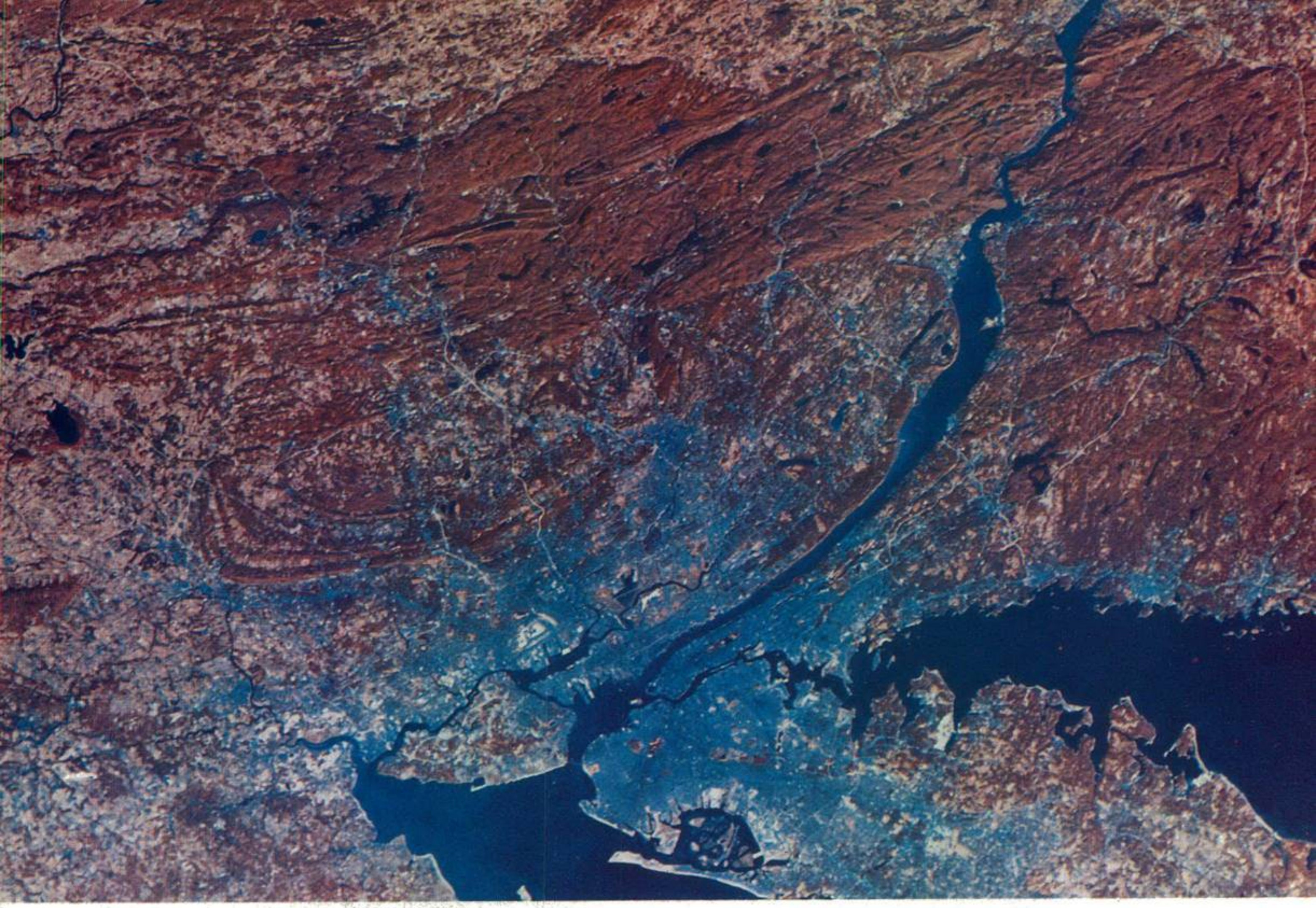
Black Holes

Black holes were "discovered" on paper in the calculations of German astronomer Karl Schwarzschild, who asked himself, "What happens if you put so much stuff in one place that space itself becomes warped?" He solved the problem mathematically in 1916. Space around a black hole is curved so tightly that nothing — not even light — can ever escape; only the gravitational attraction of the black hole mass remains. Gravitation is thus the fundamental clue astronomers have to rely on in their search for black holes.

What requirements must be fulfilled before we can say we've found a black hole and not something else "out there"? How can astronomers find something they've never seen — something that by its very nature cannot be observed directly? The search for black holes began in earnest in 1967 with the discovery of pulsars — another superdense class of objects that made it seem likely that such a thing as a black hole *could* exist. The obvious place to look for an invisible object with intense gravity was in a binary system, but no cases exhibited behavior that would point unambiguously to the existence of a black hole. If a star did have a black hole companion, some of the gas in the system would be pulled to the black hole, heating up to perhaps 10 million degrees — and emitting x-rays. But a neutron star can also emit x-rays, and it's far from simple to distinguish between the behavior of a black hole and that of a neutron star.

Astronomers now think, however, that they *have* found at least one very likely black hole: the x-ray source Cygnus X-1, also known as HD 226868. Better observations will come in 1977 with the launching of NASA's High Energy Astronomical Observatory satellite.





In the attempt to obtain close-up pictures from space of the planets, Earth itself has not been neglected. This photograph, in which green, red and infrared shots are combined, was taken from Earth Resources Technology Satellite-1, and shows New York City and the adjoining New Jersey coast. Pictures such as this have greatly increased man's knowledge and understanding of the workings of his own planet. NASA photograph.

close to the region where Harlow Shapley suspected the Milky Way's center was located.

In the years following, only a few people grasped the significance of Jansky's discovery. One was Grote Reber, a radio engineer from Illinois. Reber experimented with a homemade 30 foot radio telescope in the late thirties, looking for radio emissions from the sun, planets and stars. In 1940, he detected radio emissions from the loosely distributed gas that makes up the overwhelming volume of our galaxy.

The big problem in early radio astronomy was the discrepancies between the observed intensities of radiation at different wavelengths and their predicted values. The significant answer came 10 years later, when it was established that the radiation was not from a thermal source, but from the high acceleration of electrons in cosmic magnetic fields (a phenomenon known as *synchrotron radiation* — so named because the radiation was produced in laboratory charged-particle accelerators called synchrotrons). Reber's observations led to a map of the observable Milky Way as seen by the radio telescope. His findings also stimulated Dutch astronomer C.H. Van de Hulst to predict that hydrogen, in its neutral state, might be radio-visible at the wavelength of 21 centimeters. This was observationally verified in 1951 by Edward M. Purcell at Harvard; 21 centimeter astronomy has since become one of the most important tools for mapping our galaxy's structure.

These triumphs, combined with similar ones in solar research, established radio astronomy as possibly the most promising new field in observational astrophysics. The study flourished in England and Australia — countries which, by dire necessity during World War II, rapidly advanced radar technology and later found that wartime techniques and equipment could be directly applied to the study of the stars.

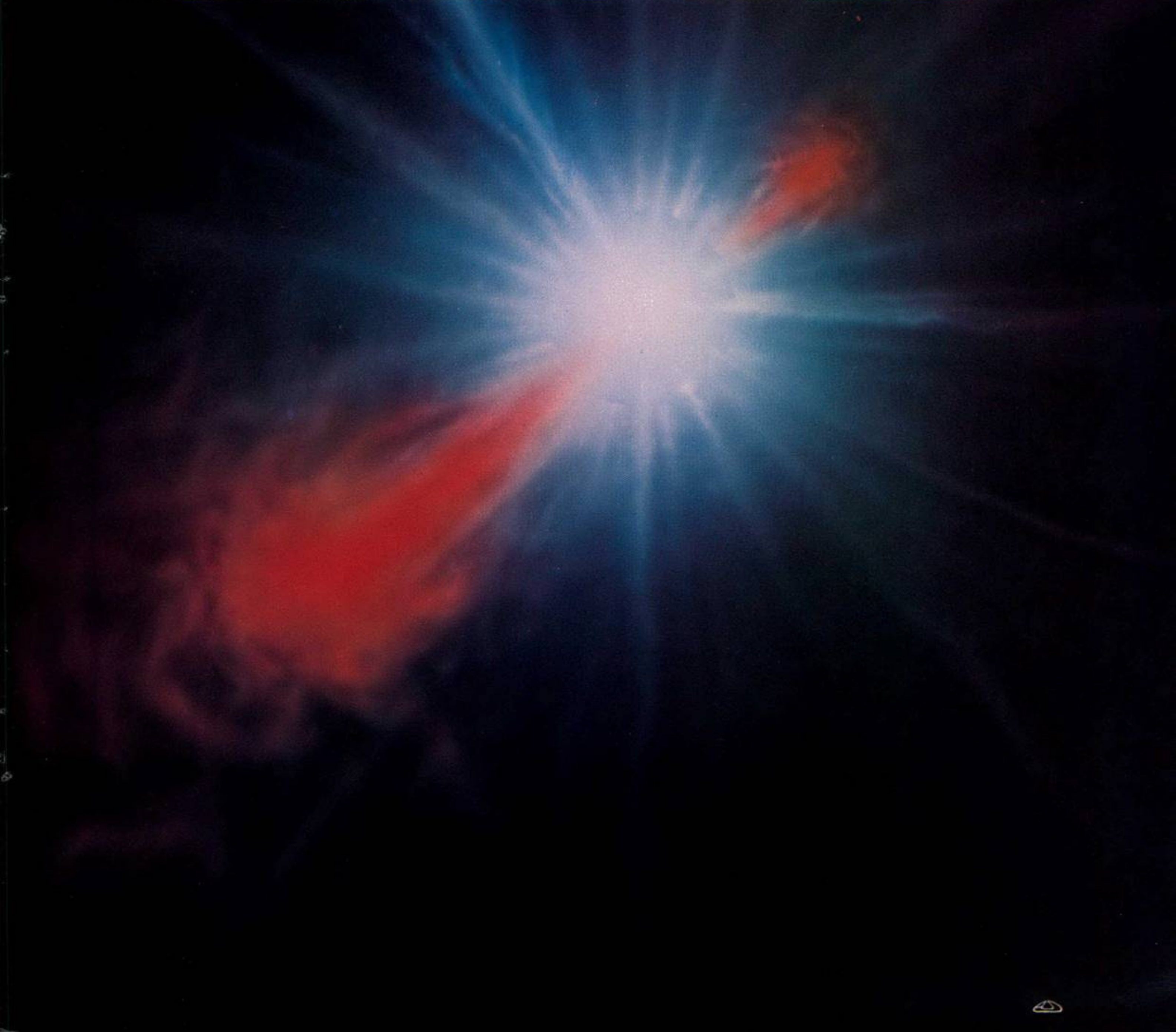
In America, interest in new radio technology lagged until the mid-1950s. Already years behind England and Australia in the development and exploitation of radio astronomy, a conference of astronomers convened in 1954 in Washington, D.C. to address the problem. The scientists decided to try to halt the widening gap by establishing a consortium of university interests to push for the construction of a National Radio Astronomy Observatory (NRAO). Such a consortium would allow for the concentration of funding into a single facility

Quasars

Quasars, very simply, are starlike objects that exhibit large redshifts. The first quasars discovered (in 1963) were sources of enormous amounts of radio energy, although some starlike objects subsequently sighted did not generate radio emissions. The term has replaced the host of names used to describe these objects: QSO (quasi-stellar object), QSRS (quasi-stellar radio source), QSS (quasi-stellar source) and BSO (blue stellar object).

The most luminous objects in the sky, quasars shine with the combined light of 1,000 galaxies, yet their sometimes rapid variations in light output reveal they can be no more than several light-days in diameter. Displaying the largest redshifts of any celestial objects, they are believed by some astronomers to lie near the limits of the observable universe, and their motions reflect the general expansion of the universe. Other cosmologists believe quasars merely appear to be distant, rapidly moving objects, when actually they are relatively nearby objects that are ejected from the nuclei of galaxies. Still other astronomers claim the properties of quasars cannot be explained by present day astrophysics.

The sources of quasars' enormous amounts of energy are unknown. Finding the solution to this and other puzzling properties of quasars (as well as the objects themselves) constitutes one of modern astronomy's most important challenges.



that would be available to all qualified investigators.

By 1959, the NRAO's 85 foot radio telescope at Greenbank, W. Va. went into operation (the site now boasts a 300 foot, partially steerable radio dish). These and larger instruments in the United States are now studying galactic structure, the enigmatic quasars and pulsars, and the nature of the interstellar medium, where, in the past few years, the existence of prebiotic macromolecules has been confirmed by radio observations. The Very Large Array (VLA) telescope, so-named because its 27 dish components give it the effective power and sensitivity of a single radio telescope 17 miles in diameter, will extend radio astronomy's reach when completed in 1981.

Today, the U.S. hosts more large radio telescopes than any other country. In Puerto Rico, Cornell University operates a gigantic 1,000 foot dish formed over a natural hollow in the steep island hills. This giant antenna, heart of the National Astronomy and Ionosphere Center, is not steerable, although the perforated aluminum dish can focus upon a small movable feed suspended hundreds of feet in the air. In this way, the telescope can scan large parts of the sky and easily examine any object in the solar system and most of the Milky Way.

One of the fundamental discoveries made with American instrumentation to date was the detection of the three degree Kelvin background radiation by a Bell Labs radio telescope operating in the microwave region of the electromagnetic spectrum. This discovery in the midsixties has been extremely important in studies of the origin of the universe. The evolutionary or "big bang" theory postulates that the observed expansion of the universe resulted from the explosion of a primordial ball of pure energy. R.H. Dicke, P.J. Peebles, and their colleagues at Princeton, had long realized that modified remnants of this initial catastrophic event might be observable, and set out to detect it. Theory showed that it would be a general field of radiation throughout the universe associated with a temperature close to absolute zero.

While the Princeton workers designed and constructed the proper instrumentation to detect the remnants of the fireball, scientists at Bell Labs, barely a half hour's drive away, were constructing a similar device to study techniques for a low noise telecommunications system that could link the Telstar and Echo satellites to ground based controls.

Following the tradition of Jansky, the Bell scientists — notably A.A. Penzias and R.W. Wilson — were trying to find all known sources of radio noise so they could be subtracted from the system when it was to be placed into operation. The two scientists took great care to identify all sources of noise, but were always left with a tiny residual which could not be identified as being caused by their instrument or any known source. Penzias heard indirectly about Peebles' and Dicke's work at Princeton and contacted Dicke. The two groups joined forces in 1965 and created a revolution in a set of comprehensive papers that appeared in the **Astrophysical Journal**. Their announcement that the universe has a background radiation temperature of 5.4 degrees Rankine (3 degrees Kelvin) provided the strongest evidence to date that the observed expanding universe is indeed the remnant of a primeval explosion.

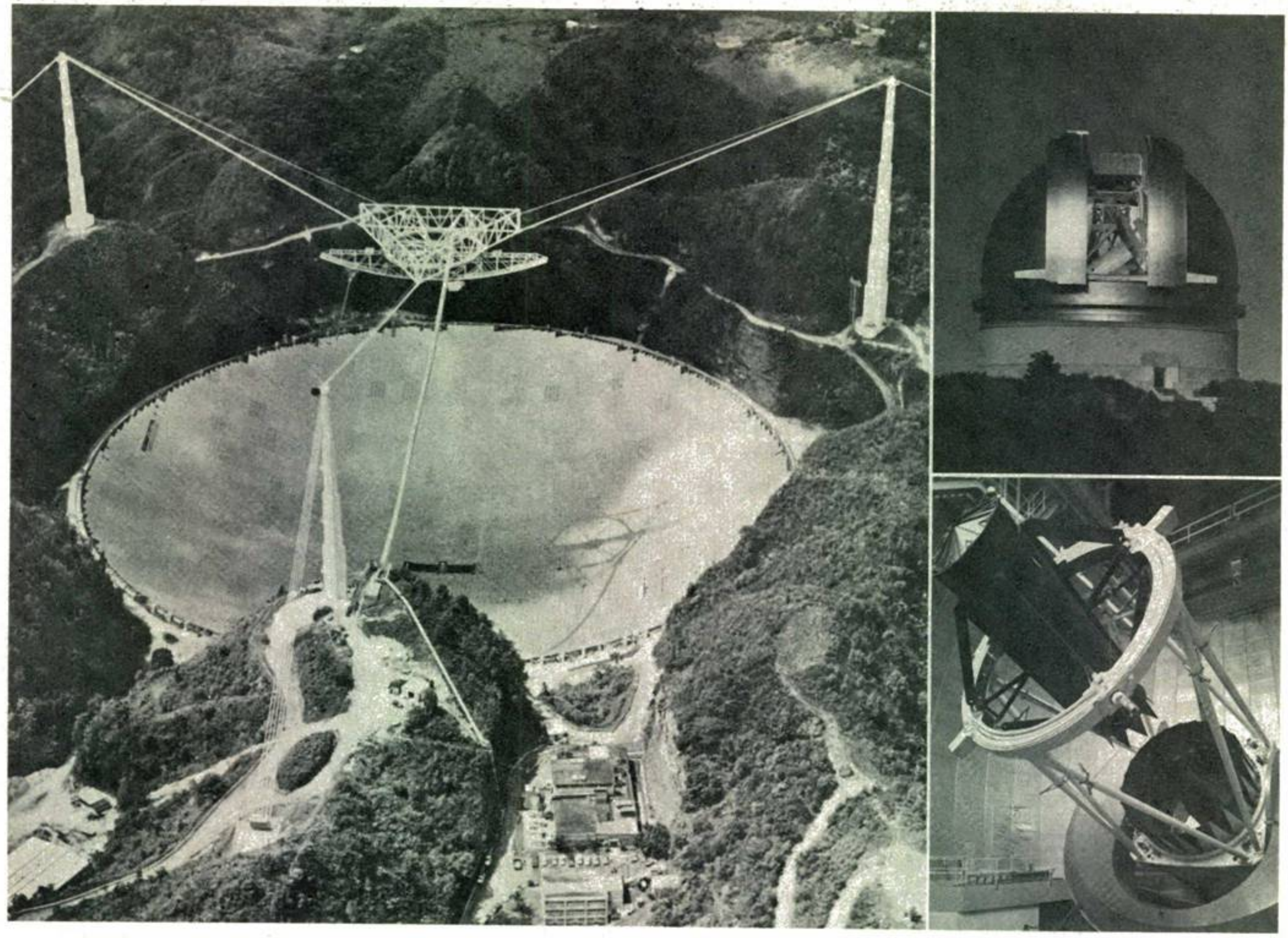
In addition to radio astronomy, there are other

Pulsars

University of Cambridge astronomers Jocelyn Bell and Anthony Hewish noticed a strange "pulsing" radio source in 1967, which turned out to be the first example of a new class of celestial object. As soon as they knew what to look for, other astronomers quickly found many more of the new objects, which were dubbed *pulsars*. Pulsars gave short sharp bursts of radio emission at regularly spaced intervals — varying from over 30 to less than 1 per second. Astronomers deduced from these signals' characteristics that they must come from small rotating objects that were gradually slowing down. The objects had to have strong magnetic fields to generate radio waves, and they had to be massive to provide driving energy.

Within a few years, theorists converged on an explanation that satisfied all the requirements: A pulsar had to be a tiny superdense core of a star — with a mass equal to the sun's but a diameter of only 15 miles — formed in the colossal explosion of a supernova. This tiny core retained much of the original star's rotational energy and its magnetic field, compressed into a tiny dense ball called a neutron star. Its intense magnetic field interacts with nearby gas to create radio energy, directing this energy in a narrow beam that sweeps past Earth each time the neutron star rotates. The loss of energy slows the star down, and its rotational period gradually becomes longer over the centuries.

Today, pulsars and neutron stars are fairly well understood. Their discovery has increased our knowledge of physics and led to a better understanding of many other objects in the universe.



Left: The 1,000 foot diameter reflector of the Arecibo radio telescope at Arecibo, Puerto Rico, resides in a naturally formed bowl. Photograph by Cornell University. At upper right is a moonlit view of the dome housing the 200 inch Hale telescope at Mount Palomar. Hale Observatories photograph. Pictured at lower right is the Kitt Peak 158 inch Mayall telescope. Kitt Peak National Observatory photograph copyright© by the Association of Universities for Research in Astronomy, Inc.

"invisible astronomies" that in the past few years have expanded our vision of the universe. X-rays, gamma rays and neutrinos are now being studied with sensors as alien to the classic astronomical telescope as the computer is to the abacus.

Rocket and balloon-borne detectors riding above Earth's protective atmospheric envelope have studied x-ray sources such as the Crab nebula (M-1), the site of a vast supernova explosion expanding into space from a highly compressed stellar remnant called a neutron star. Once the wild dream of theoreticians, neutron stars make their presence known as pulsars — those rapidly rotating radio sources first discovered in 1967.

The elusive neutrino, a subatomic particle without mass or electric charge, and able to pass through Earth virtually unaffected, can only be detected by such strange "telescopes" as Dr. Raymond Davis Jr.'s vast tank of tetrachloroethylene placed in a mile-deep mine shaft under Lead, S.D. The experiment was devised to detect neutrinos produced by the sun. When a neutrino encounters an isotope of chlorine in Davis' neutrino trap, the chlorine changes into argon-37 with the emission of an electron. If an event happens, the detection of argon would tell the tale. Preliminary experimental results demonstrate that less than half the predicted number of neutrinos are emitted from the sun's center. Either the theory of energy production in the sun is incorrect, many different types of neutrinos exist, or we know far less than we thought we did about the sun. The astronomer can no longer boast that we know more about the center of the sun than we do about the center of Earth.

Possibly the most fascinating new realm in astronomy, the study of galactic x-ray sources is providing data about the physical nature of objects compressed by gravitation to the ultimate limits of observability — black holes. Believed to be the final stages of life of high mass stars, these incredibly dense objects bend and redden any optical emissions from their surface to such an extent that the light cannot leave them. The x-ray source called Cygnus X-1 is believed to be the site of such a star. Detected by the Uhuru satellite, an international project funded by NASA and involving American industrial expertise, the source of the x-rays seems to be an otherwise invisible region orbiting a visible star where, from analysis of the orbit, the mass of the invisible x-ray source exceeds the sun's. If Cygnus X-1 is a black hole, we might ponder what

Man on the Moon

From the Apollo 11 astronauts on the moon:

Neil Armstrong: "I'd say the color of the local surface is very comparable to that we observed from orbit. . . . It's pretty much without color. It's gray, a chalky gray . . . and a darker, ashen gray."

Edwin Aldrin: "Looks like a collection of just about every variety of shape, angularity, granularity, about every variety of rock you could find. Color depends on what angle you're looking at."

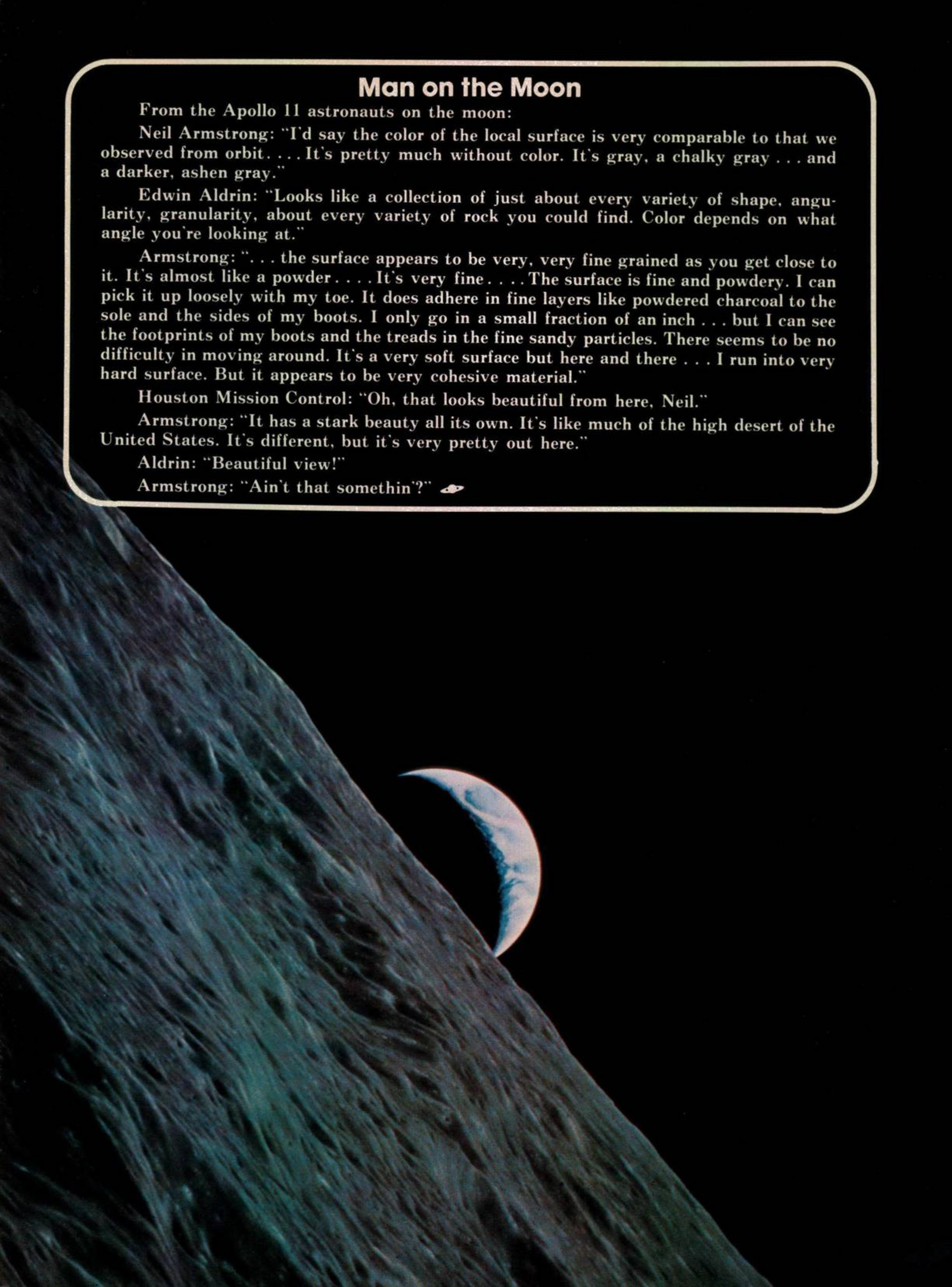
Armstrong: ". . . the surface appears to be very, very fine grained as you get close to it. It's almost like a powder. . . . It's very fine. . . . The surface is fine and powdery. I can pick it up loosely with my toe. It does adhere in fine layers like powdered charcoal to the sole and the sides of my boots. I only go in a small fraction of an inch . . . but I can see the footprints of my boots and the treads in the fine sandy particles. There seems to be no difficulty in moving around. It's a very soft surface but here and there . . . I run into very hard surface. But it appears to be very cohesive material."

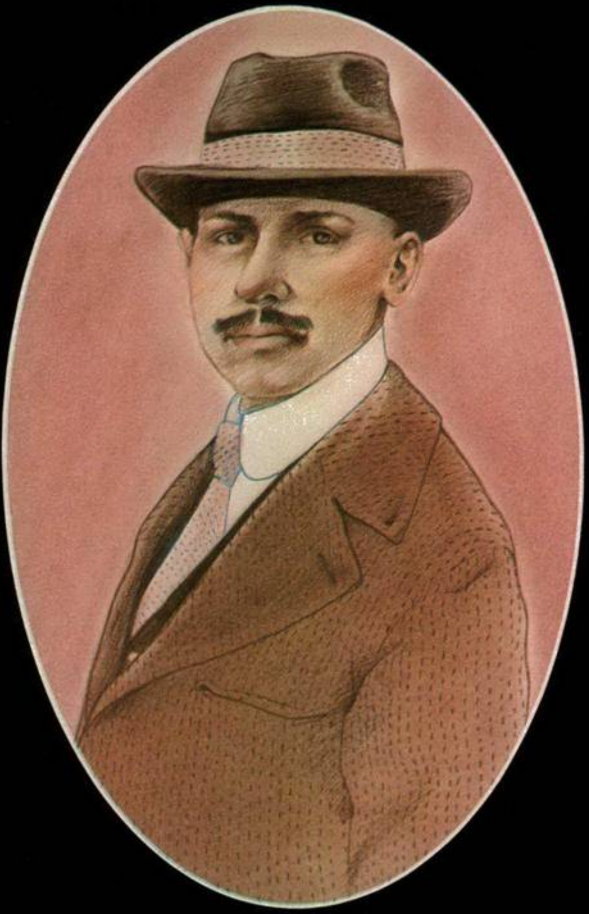
Houston Mission Control: "Oh, that looks beautiful from here, Neil."

Armstrong: "It has a stark beauty all its own. It's like much of the high desert of the United States. It's different, but it's very pretty out here."

Aldrin: "Beautiful view!"

Armstrong: "Ain't that somethin'?"





Robert H. Goddard (1882-1945)

American physicist Robert H. Goddard was the first to put into practice the idea of using rockets to explore the upper atmosphere and outer space (an idea independently conceived by Goddard and the Russian teacher, Konstantin Ziolkovsky), but his ideas and experiments received little attention and even less support from his contemporaries.

Goddard wrote a short pamphlet published by the Smithsonian Institute in 1920 — *A Method for Reaching Extreme Altitudes* — which discussed whether rockets could be used as instrument carriers for the investigation of Earth's upper atmosphere. The idea, Willy Ley later reported, was not the subject of a great deal of scientific debate.

Disheartened, Goddard devoted himself to controlled propulsion through use of liquid fuels. The first successful flight of a rocket using liquid fuel occurred on March 16, 1926 near Goddard's home in Auburn, Mass. The only people aware of the 184 foot, 2.5 second flight were Goddard's neighbors, who subsequently succeeded in having him ordered to take his experiments elsewhere.

Goddard moved to New Mexico in 1930, eventually conducting several rocket flights that reached heights of 7,500 feet and speeds of over 550 m.p.h. Although the U.S. Navy halfheartedly supported Goddard's work during World War II (he died at the end of the war), his foresight and persistence provided the foundation for America's later success in space exploration.

Planetary Probes — Close-ups on Other Worlds

"A man's reach should extend his grasp, or what's a heaven for?" — Robert Browning.

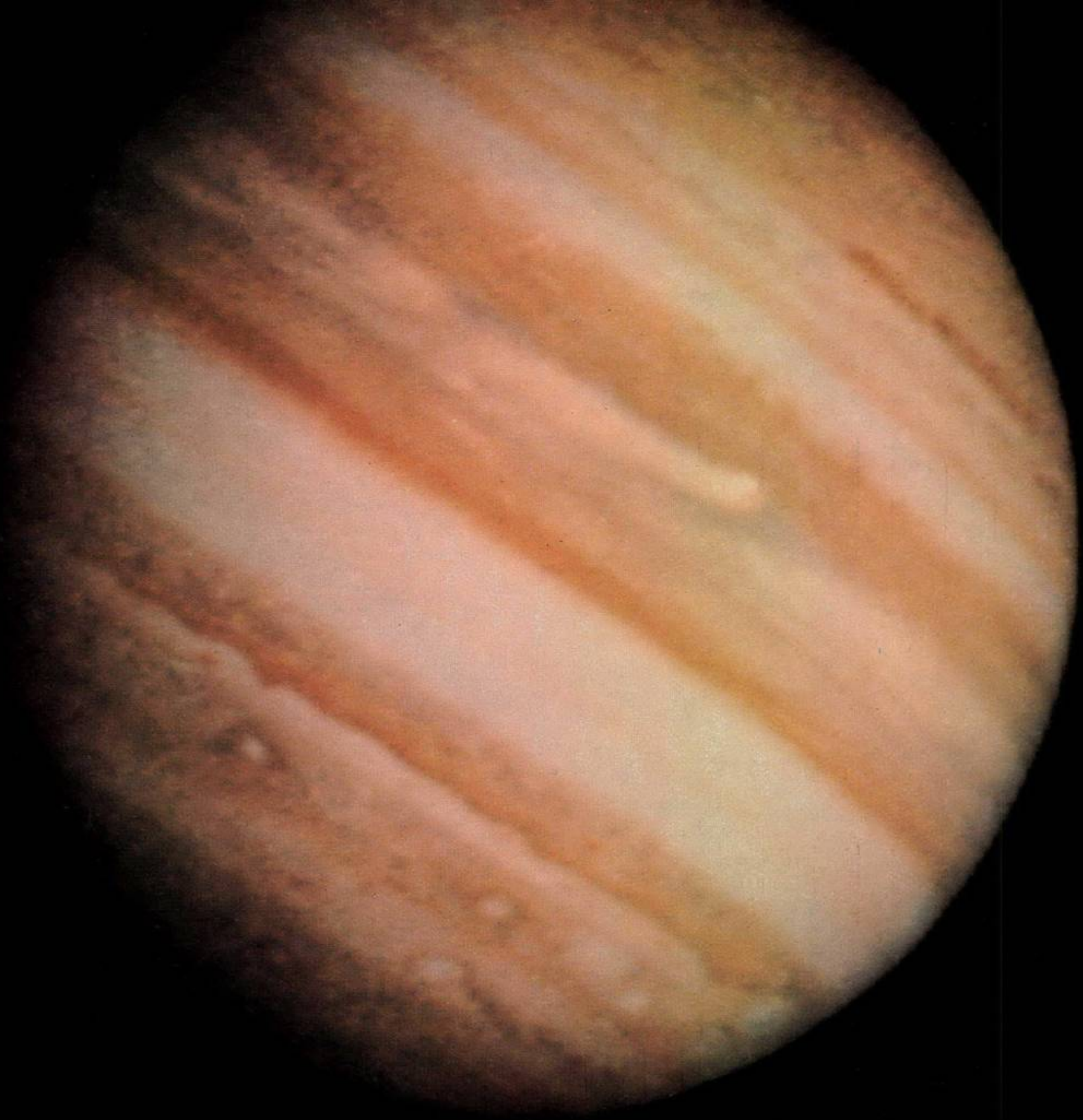
A perusal of many of the astronomy texts published during the 1950s gives a somewhat disturbing view of our solar system. A tacit assumption behind most discussions of the planets seems to be that all the basic facts were known and further investigation, while of possible academic interest, would provide little or no new information.

Less than 20 years later, our conceptions of the individual planets have changed so drastically that current texts become outdated almost annually. The unmanned Mariner and Pioneer probes have greatly extended man's reach without his having to leave Earth at all.

The 1962 Mariner 2 probe to Venus and the 1965 Mariner 5 flyby of Mars shattered many cherished illusions; they revealed that the atmosphere of Venus was unlivable, that Mars was covered with craters, not canals, and delivered the death blow to the intricate life systems that had been postulated for each planet. More than anything else, it took these two probes to convince many scientists that there was more to the solar system than met the telescopic eye.

Subsequent expeditions have mapped the surface of Mercury, revealed the composition — and utter hostility — of Venus' cloud cover, and given man the awesome close-up spectacle of Jupiter. The ability to *see*, for the first time, what the planets are actually like has provided the impetus for constant further investigation.

Perhaps the most significant discoveries have been of the changing surface of Mars, proving that the red planet is by no means a "dead" world. The Viking missions, scheduled to land in July 1976, will attempt to answer the most urgently debated topic of all: Does life exist elsewhere in our solar system?

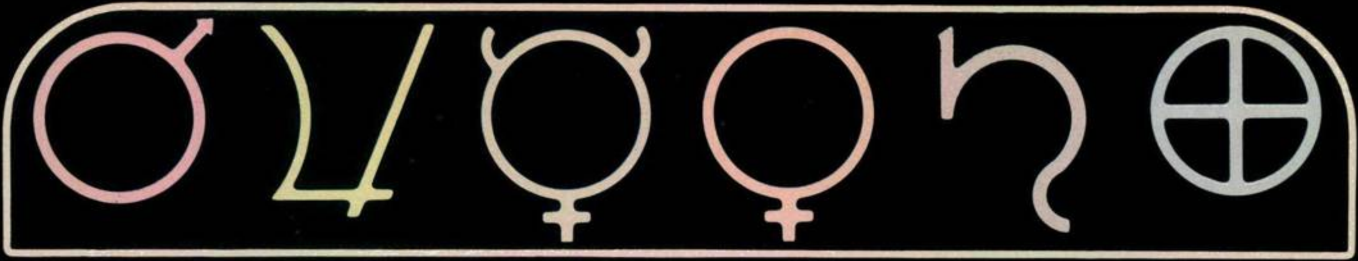


it is that we are "seeing". X-rays do not emanate from the surface of the object, but from a region around it, where matter falling in from its stellar companion has been accelerated to relativistic velocities, thus becoming "visible" in the x-ray portion of the spectrum.

Space astronomy has come into its own in the past decade. No longer are we limited by our turbulent, polluted atmosphere. Just as 19th century American astronomers scaled mountains in the Rockies and the coastal ranges of California, modern astrophysicists now analyze data about the sun, planets, comets, stars, nebulae and galaxies derived from orbiting astronomical telescopes. The OAO and OSO projects, Skylab and the Space Telescope, to be carried aloft by the Space Shuttle, will revolutionize astronomy.

Man in space, man on the moon and unmanned emissaries to the planets have created an entirely new aspect of astronomical study. Until recently, the objects of astronomical interest have been remote and untouchable. While direct experimentation rose in other sciences, astronomy was left peering at celestial objects from unfathomable gulfs of space. No longer is this true. Rocks and soil samples from the moon and direct probes to the vast and turbulent magnetic sheath surrounding Jupiter have called to the oldest of the physical sciences the newest techniques known to the physicist, engineer and chemist. This month, July 1976, will see the culmination of the first page of space exploration with the landing of a craft on an extraterrestrial surface as similar to Earth's as is known in the universe — the planet Mars.

Hopefully, this first page is merely the preface to a never ending tale of scientific endeavor. When the time comes to write the tercentenary view of American astronomy, this prelude will usher in a continuing story every bit as exciting and valuable as the first 200 years of astronomy in America.



SKY ALMANAC

Nowhere to Go But Up

This month, with the disappearance of Saturn, the nearness to the sun of Venus and Mercury, and the continued fading of Mars, the possibilities for satisfactory planetary observation hit rock bottom for 1976. Only Jupiter and the Delta Aquarid meteor shower will prevent July from being a complete disappointment to solar system watchers. We might derive some comfort from the thought that, from this time on, conditions can only improve.

Mercury, Venus

The two inner planets lie too close to the sun to be easily spotted throughout July. Mercury, in fact, reaches superior conjunction on the 15th and is located on the opposite side of the sun from Earth. On the same date, Venus reaches perihelion — the point in its orbit at which it lies closest to the sun.

Having passed its own superior conjunction last month, Venus is now an evening star — still not very high above the horizon, but, at magnitude -3.4, bright enough to be glimpsed by those who have a clear view to the northwest. A good opportunity for observing both inner planets at once is provided on the evenings of the 23rd and 24th, when Mercury and Venus will lie within two degrees of each other. If you find Venus low in the west, binoculars or richest-field telescopes should allow you to locate Mercury in the same field of view. Mercury will be almost exactly zero magnitude both evenings. The two planets make their closest approach (as seen from Earth) on the morning of the 24th, when they are separated by only 0.4 degrees.

Mars

Mars' magnitude for all of July is +1.9; it will remain this dim until early October. Its distance from Earth increases from 202 million miles on the 1st to 217 million miles by month's end. On the evening of the 5th, look for Mars in the constellation Leo; the planet will lie less than a degree from first magnitude Regulus. Mars can be distinguished by its red color (in contrast to the star's blue-white) and by the fact that it will be slightly dimmer than +1.36 magnitude Regulus. Mars moves slowly through Leo during the rest of July.

Jupiter

The largest planet moves from Aries into Taurus on July 2. It rises about midnight and is now well up in the east at sunrise. During July, Jupiter moves from 522 to 486 million miles from Earth; accordingly, its diameter increases from 32.7 to 35.1 seconds of arc. As Jupiter rises earlier, its satellites become easier to see; ASTRONOMY will resume its "Satellites of Jupiter" chart next month. On July 31, the giant planet lies less than five degrees from the Pleiades. Its magnitude is -1.8 most of the month.

Saturn

Saturn is too close to the sun this month to be observed; it will be at conjunction on July 29, at which time the planet will be at its maximum distance from Earth of nearly 941 million miles.

Uranus, Neptune

On July 11, the planet Uranus is stationary; it ceases its retrograde motion and resumes its forward path among the stars. Uranus can still be found in the early evening, but July will be the last month for easy observation of the planet.

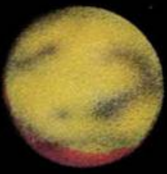
Neptune is still in an excellent position for observing. In southern Ophiuchus, it is on the meridian during the early hours of July nights.

Meteors

The Delta Aquarid meteor shower reaches its peak about July 28. The shower, so called because its radiant point lies near the star Delta Aquarii, stretches from the latter half of July through August, and actually consists of several fairly weak showers. The usual rate is 15 to 20 meteors per hour around the peak date. Since the moon is just past new on the 29th, it will not interfere with observation.

The photo of comet West (opposite page, upper left) was taken on March 8, 1976 when intricate structural detail was visible in the tail. The 3-1/2 minute guided exposure on GAF 200 was obtained with a 135mm lens at f/2.8. Photograph by E. Jay Sarton. The second comet West photo was made on March 11 at the Garden of the Gods in Colorado. This is a 20 second exposure, using a 50mm lens at f/2.8. Photograph by Frank Calloway. At upper right are two planet photos; the shot of Jupiter is a five second exposure on Kodachrome 64 through a Celestron 8. Photograph by Bob Somerville. A 10 inch f/6 Cave Newtonian was used for Saturn; the exposure was 1-1/2 seconds on High Speed Ektachrome pushed to ASA 400. Photograph by Lance Olkovick. At bottom, a 30 minute exposure of the Milky Way in Sagittarius was obtained through a 50mm lens at f/2 on High Speed Ektachrome. Photograph by Stephen Reed.

Planet Finder



Ⓒ Ceres

July	1	15
R.A.	$7^{h}38^{m}$	$8^{h}06^{m}$
Dec.	+26°12'	+25°21'
Mag.	+8.8	+8.8

Ⓐ Mercury

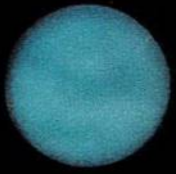
July	1
R.A.	$5^{h}38^{m}$
Dec.	+22°26'
Mag.	-0.7

Ⓑ Mercury

July	15
R.A.	$7^{h}44^{m}$
Dec.	+22°49'
Mag.	-1.8

Ⓜ Mars

July	1	15
R.A.	$9^{h}58^{m}$	$10^{h}30^{m}$
Dec.	+13°36'	+10°27'
Mag.	+1.9	+1.9



Ⓝ Neptune

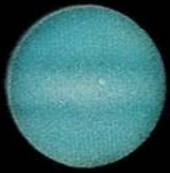
July	15
R.A.	$16^{h}41^{m}$
Dec.	-20°37'
Mag.	+7.7

SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

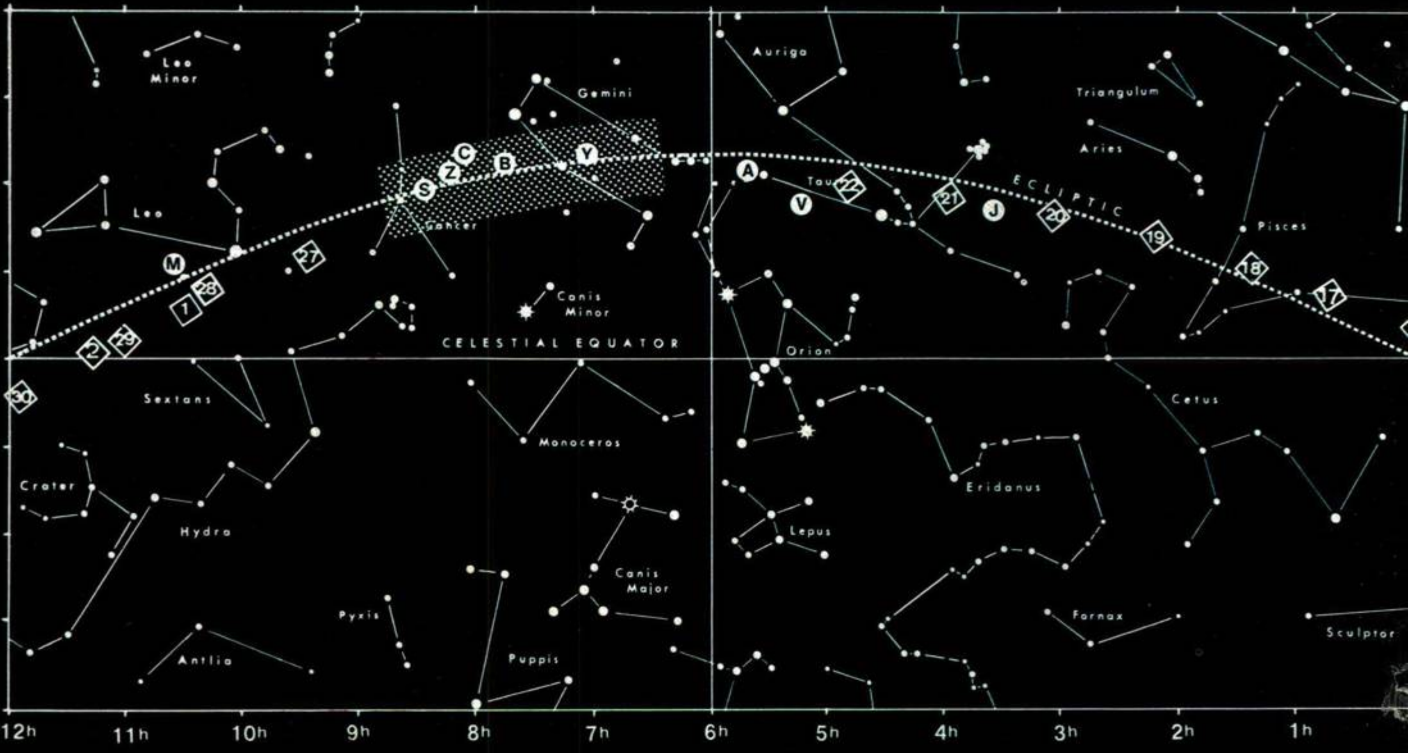
Ⓢ Saturn

July	1	15
R.A.	$8^{h}21^{m}$	$8^{h}29^{m}$
Dec.	+19°56'	+19°32'
Mag.	+0.5	+0.5



Ⓤ Uranus

July	15
R.A.	$14^{h}03^{m}$
Dec.	-12°04'
Mag.	+5.7


Leo Minor
Gemini
Auriga
Triangulum
Aries
C
Y
S
Z
B
A
Taurus
22
21
ECLIPTIC
V
J
20
Leo
Cancer
19
Pisces
M
27
18
28
7
Canis Minor
17
2
29
CELESTIAL EQUATOR
Orion
30
Sextans
Cetus
Monoceros
Crater
Eridanus
Hydra
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec . = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag . = magnitude, a

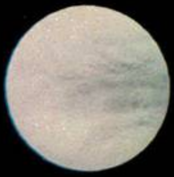
July 1976

Ⓥ Vesta

July	1	15
R.A.	4h54m	5h18m
Dec.	+19°12'	+19°54'
Mag.	+9.0	+8.9

Ⓙ Jupiter

July	1	15
R.A.	3h20m	3h31m
Dec.	+17°24'	+18°01'
Mag.	-1.7	-1.8



Ⓨ Venus

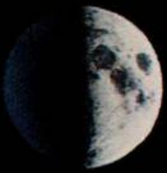
July	1
R.A.	7h01m
Dec.	+23°27'
Mag.	-3.5

Ⓩ Venus

July	15
R.A.	8h15m
Dec.	+21°01'
Mag.	-3.4

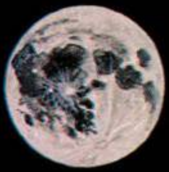
Ⓟ Pluto

July	15
R.A.	12h58m
Dec.	+11°57'
Mag.	+14



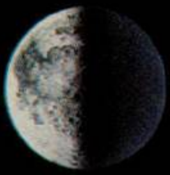
First Quarter

July 4



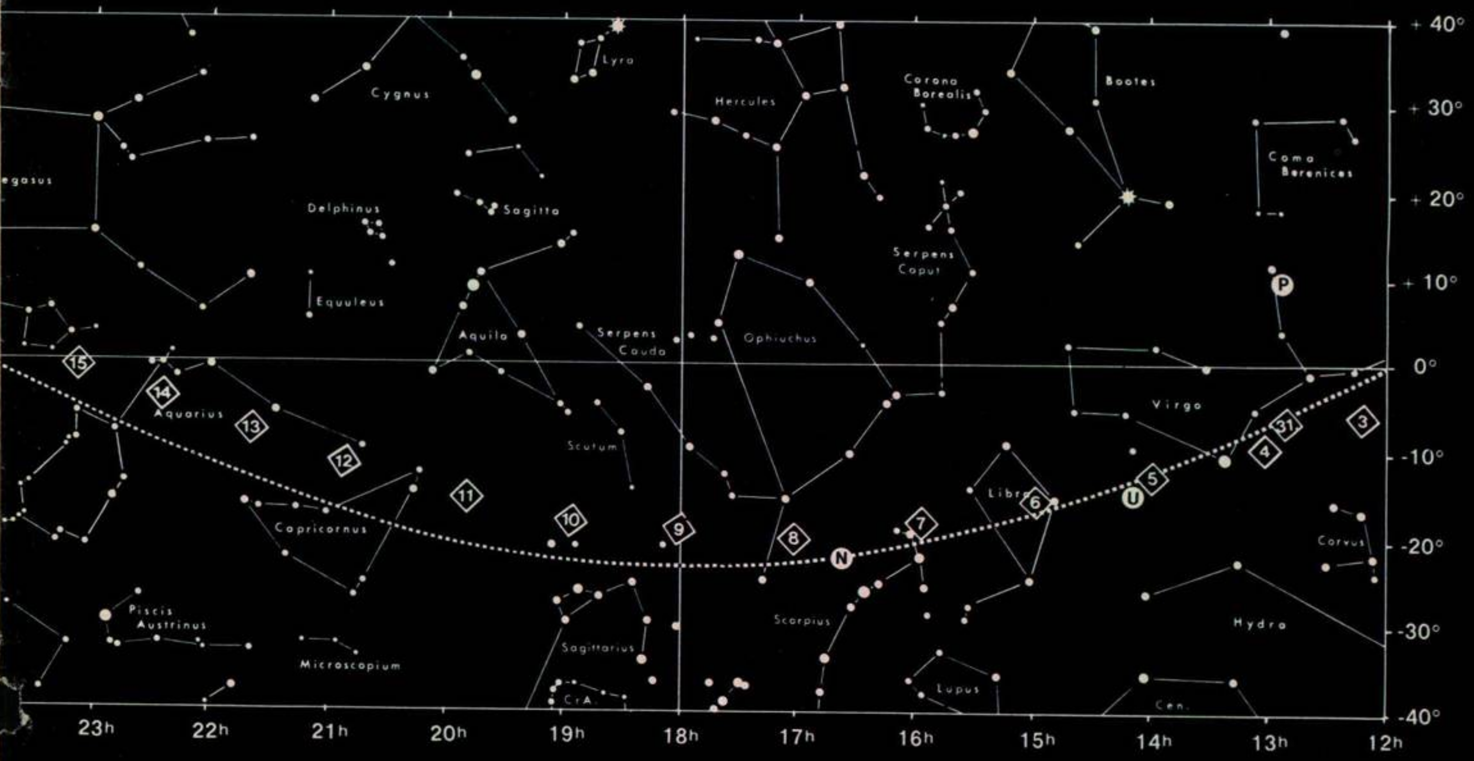
Full Moon

July 10



Last Quarter

July 18


+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h
Pegasus
Cygnus
Lyra
Hercules
Corona Borealis
Bootes
Coma Berenices
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Piscis Austrinus
Microscopium
Sagittarius
Scorpius
Hydra
Lupus
C.A.
Cen.
P
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13
12
11
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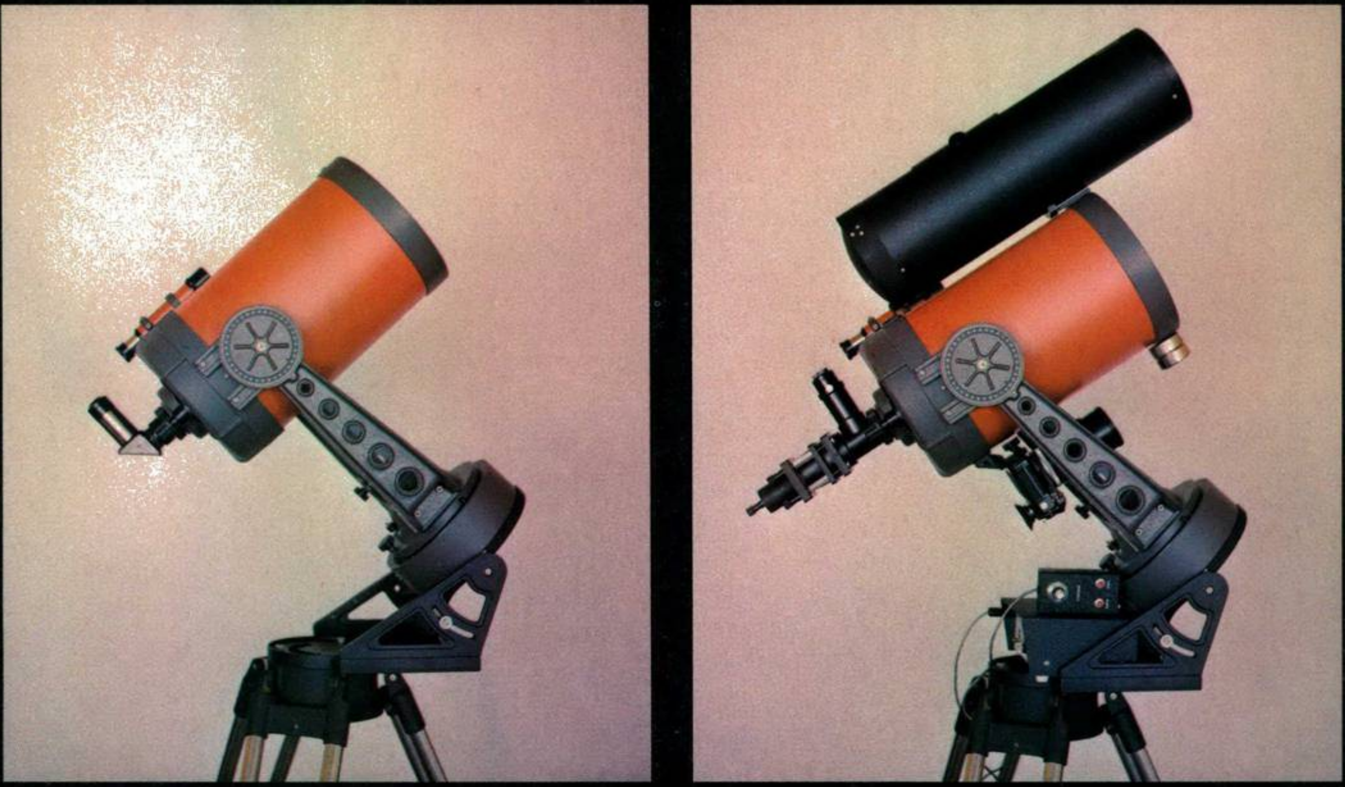
5
4
31
3

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.

Today the basics are enough. But tomorrow they might not be.



Whether you're an amateur astronomer or a professional astronomer, the chances are that in the future your needs will change or grow.

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Because maybe today the basics aren't enough.
But tomorrow they might be.

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Celestron

LEFT: The basic Celestron 8, with setting circles and electric clock drive ($790), mounted on equatorial wedge and tripod for observations in the field. The simplicity of this system has helped make the Celestron 8 the world's best-selling compact-portable telescope. RIGHT: The Celestron 8, as it might be set up for multiple-field deep-sky photography, with a telephoto lens and a Celestron Schmidt Camera mounted piggyback, and a 35mm cold camera mounted at first focus behind the Celestron off-axis guiding assembly.